Igneous Processes in the Welsh Basin

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In recent years I have had the pleasure of conducting field courses for OUGS members in the Harlech Dome, Lleyn Peninsula and Pembrokeshire. In each area interest centered on volcanic and intrusive rocks within the Precambrian and Lower Palaeozoic sedimentary successions, and plate tectonic models were prominent in discussions of their origins. This article reviews current ideas about the role of igneous processes in the development of the Welsh Basin.

In 1938 Professor O. Jones established the concept of the Welsh Lower Palaeozoic geosyncline, and this model was widely accepted until the advent of plate tectonics. The geosynclinal model identified an elongated subsiding trough oriented NE-SW across the Welsh area, bordered to the northwest by a land area, in the region of Anglesey, termed the Irish Sea Landmass. To the southeast the basin merged into a stable shelf sea, in what are now the English Midlands, where subsidence was minimal; this was known as the Midland Platform.

The Caledonian orogenic cycle in Wales was identified with the filling of the Welsh geosyncline by Cambrian, Ordovician and Silurian marine sediments to an ultimate thickness of 10km, followed by compression of the sedimentary sequence in Late Silurian to Devonian times to produce Caledonian fold structures. It was considered a normal feature of geosynclinal development that a phase of eruption of submarine volcanics should occur at the middle of the sedimentary infilling sequence, and this was correlated with the extensive development of volcanics in the Ordovician strata of Snowdonia, the Harlech Dome and Pembrokeshire. Major granite intrusions in Snowdonia were regarded as of Caledonian orogenic origin.

It is an interesting feature of the geosynclinal model that the Precambrian rocks of Anglesey and Pembrokeshire were regarded as ancient basement unrelated to the Caledonian sedimentary cycle. To the northwest of the Irish Sea Landmass there was considered to be another subsiding basin occupying the Southern Uplands of Scotland and the Lake District, termed the Moffat geosyncline. A similar sequence of sedimentation, volcanicity and orogenesis was identified in this region.

In the late 1960s geologists began to appreciate the mechanisms of ocean floor spreading, with the identification of active mid-ocean spreading ridges and destructive plate margins of island arc and Andean types. Igneous processes were clearly involved in both the production of new oceanic crust and the subduction of oceanic crust into the mantle.

A major advance in our understanding of the Caledonian sedimentation and orogenic cycle in Wales came in 1969 with the introduction of a plate tectonic model by Dewey, based on analogy with present day tectonic processes. From Proterozoic times of the Precambrian an ocean basin roughly parallel to the present Atlantic began to open along a line from northern Norway, through Britain and Ireland, to Newfoundland and the Eastern States of the USA. Sedimentation at or near the margins of this basin constituted the sedimentary successions of the earlier geosynclinal model. The ocean, called Iapetus, continued to expand by production of new oceanic crust at a spreading ridge, but subduction zones became active at the ocean margins from Late Proterozoic times onwards. Lavas and igneous intrusions were produced as magma generated along the subduction zones rose through the overlying crust. Closure of the basin was completed in Upper Silurian and Lower Devonian times, with the final compression of sediments between the converging continental forelands resulting in Caledonian fold structures. It should be noted that at least part of the Precambrian succession of Anglesey is included in the

Caledonian cycle of sedimentation and orogenesis in Dewey's model.

The line along which the Iapetus opened is thought to lie in the border country between England and Scotland. Late Precambrian and Lower Palaeozoic strata south of this line were thus deposited at the southern continental margin of the ocean basin, whilst successions of similar age in Scotland were deposited at the northern continental margin. The extent of the ocean basin is indicated by a study of Lower Palaeozoic brachiopod and trilobite faunas. These phyla possessed free swimming larval forms, so could colonise the length of a shoreline. They were, however, restricted in crossing a wide ocean basin due to the limited survival times of larvae in open water. A comparison of the brachiopod and trilobite faunas of sediments of the northern and southern margins of Iapetus indicates increasing evolutionary divergence during Cambrian times as the basin reached its maximum width. During the Ordovician mixing of species between the ocean margins increased until a uniform fauna was again established by the end of the Silurian period.

Examination of the geology of recently active destructive plate margins such as the Japan island arc reveals characteristic tectonic and igneous features. The subduction process can produce folding and underthrusting as sediments are carried downwards from the ocean trench with the subducting oceanic plate, resulting ultimately in metamorphism to schist grade. At greater depths along the subduction zone high temperature metamorphism can produce gneisses, or magma may be released upwards as diapirs to form high level intrusions or to be erupted at the surface as volcanics. Identification and dating of similar features within the sedimentary successions bordering the Iapetus allows a reconstruction of the tectonic history of the ocean basin. Wright has shown that separate phases of subduction occurred alternately at the northern and southern basin margins as the Caledonian cycle progressed from the Late Precambrian to Silurian times.

The earliest phase of subduction is thought to have occurred at the northern margin of Iapetus during the Precambrian, at a date of approximately 1000Ma. Moine greywacke sediments deposited in the earliest stages of the opening of Iapetus were intensely folded and metamorphosed to schist, and in places to gneiss, grade. This tectonic and metamorphic event has been termed the Morar orogeny. Subduction then appears to have stopped at the northern continental margin, to recommence at the southern margin in Late Precambrian times around 600Ma. The event affected the Precambrian sedimentary succession of Anglesey known as the Mona group, resulting in the production of schists and gneisses accompanied by igneous intrusions and volcanics erupted above the subduction zone. This phase is termed the Celtic orogeny.

Following the Celtic orogeny, subduction reverted to the northern margin of Iapetus. Here the great thickness of Dalradian sediments deposited near the continental margin after the Morar event were deformed in the Grampian orogeny. This has been dated as Tremadoc (Late Cambrian) to Arenig (Early Ordovician) in age. Deformation and metamorphism was intense, producing nappe fold structures and a zonation into schists and gneisses in the Grampian Highlands.

Subductive activity resumed at the southern margin of Iapetus during Ordovician times, resulting in a modest fold event in the Lake District but a widespread outburst of volcanic activity above the subduction zone in both the Lake District and Wales. This event has been termed the Lakelandian orogeny, but its tectonic and metamorphic effects are minimal. By Silurian times subduction was operating on both continental margins, leading to final closure of the Iapetus basin. A final orogenic event, the Caledonian itself, occurred at the end of the Silurian and the beginning of the Devonian as sediments were compressed between the converging forelands. Folding associated with this event was most intense in the Southern Uplands of Scotland, decreasing in intensity southwards to Wales.

Wright has proposed a model to explain the alternation of subduction between the northern and southern margins of the Iapetus basin. Oceanic lithosphere is generated at the mid-ocean ridge system by the eruption of basalt lavas onto

the sea floor and intrusion of basic and ultrabasic dykes in the opening fissure separating the diverging plates. The igneous materials are initially hot, and so of relatively low density. As the new oceanic crust is carried away from the mid-ocean ridge cooling and contraction take place and the density of the oceanic plate increases. After a period of, perhaps, 50Ma the density of the cooling oceanic plate becomes sufficient to allow it to descend into the underlying hot, lower density, mantle, and subduction commences.

The effect of subduction occurring at only one margin of an ocean basin is to displace the mid-ocean ridge towards that margin. Increasingly younger, and consequently hotter, oceanic crust will be arriving at the subduction zone until a point is reached when the density of the oceanic plate is too low for descent into the mantle; subduction then ceases. By this time, however, the spreading ridge will have migrated sufficiently far from the opposite basin margin for oceanic lithosphere at that point to be cool and of high density. Hence subduction recommences at this opposite margin. The cycle is thought to have occurred several times during the lifetime of the Iapetus Ocean. When the mid-ocean spreading centre finally became inactive, towards the Silurian period, oceanic lithosphere on both sides of the basin could cool to the point where subduction commenced, and closure of the basin was effected by subduction both to the north and south.

The plate tectonic model for the Caledonian orogenic cycle clearly implicates the Precambrian sedimentary succession of Anglesey and the Lleyn Peninsula in the early history of the Iapetus Ocean. Anglesey presents more problems for the geologist than perhaps any other area of Wales, and considerable revisions in interpretation have taken place since the initial mapping of the island by Greenly in 1919. Controversy still continues concerning the ages of some sedimentary and metamorphic formations, and observers are invited to choose between a variety of plate tectonic models for the Celtic orogenic event.

The rocks of Anglesey and the Lleyn Peninsula traditionally considered to be of Precambrian age are known as the Mona Complex. They are unconformably overlain at various localities by Ordovician and younger strata. The Mona Complex can be divided lithologically into:

- a sequence of bedded sediments and volcanics of low metamorphic grade
- a group of higher metamorphic grade schists and gneisses.

The bedded series can be divided further into:

- an older group of clastic sediments, including greywackes, quartzites and siltstones, probably deposited in deep water
- a younger group of more varied and unusual rock types, including oolitic limestone, volcanic ash and basalt pillow lavas. This group is called the Gwna Formation.

The Gwna Formation is particularly interesting as it is largely in the form of a massive breccia, known as a melange. This consist of blocks of limestone, sandstone and other lithologies set in a matrix of muddy material. Individual clastic blocks range in size from centimetres to over a kilometre in length, and a ghost stratigraphy can be traced through the melange with blocks of one lithology separated considerably in the direction of the bedding. It has been suggested by Shackleton (1969) that the Gwna melange was formed by slumping of sediments down a submarine slope whilst still semi-lithified.

The higher grade metamorphic rocks of the Mona Complex, the schists and gneisses, are still causing some difficulty in interpretation. At several localities, most particularly at Parwyd at the south-west tip of the Lleyn Peninsula, Shackleton has demonstrated that the schists are a metamorphic equivalent of the bedded sequence; a gradational contact exists between the two formations. The schists show a tectonic foliation, and appear in places to have been formed from the bedded series by repeated small-scale shearing along mylonite zones. A difference of opinion exists, however, concerning the relationship between the schists and gneisses. In the original mapping of Anglesey, Greenly considered the gneisses to be Archaean basement brought to the surface by faulting, and consequently considerably older than the schists and bedded series. Shackleton, on the other hand, demonstrated possible gradational contact

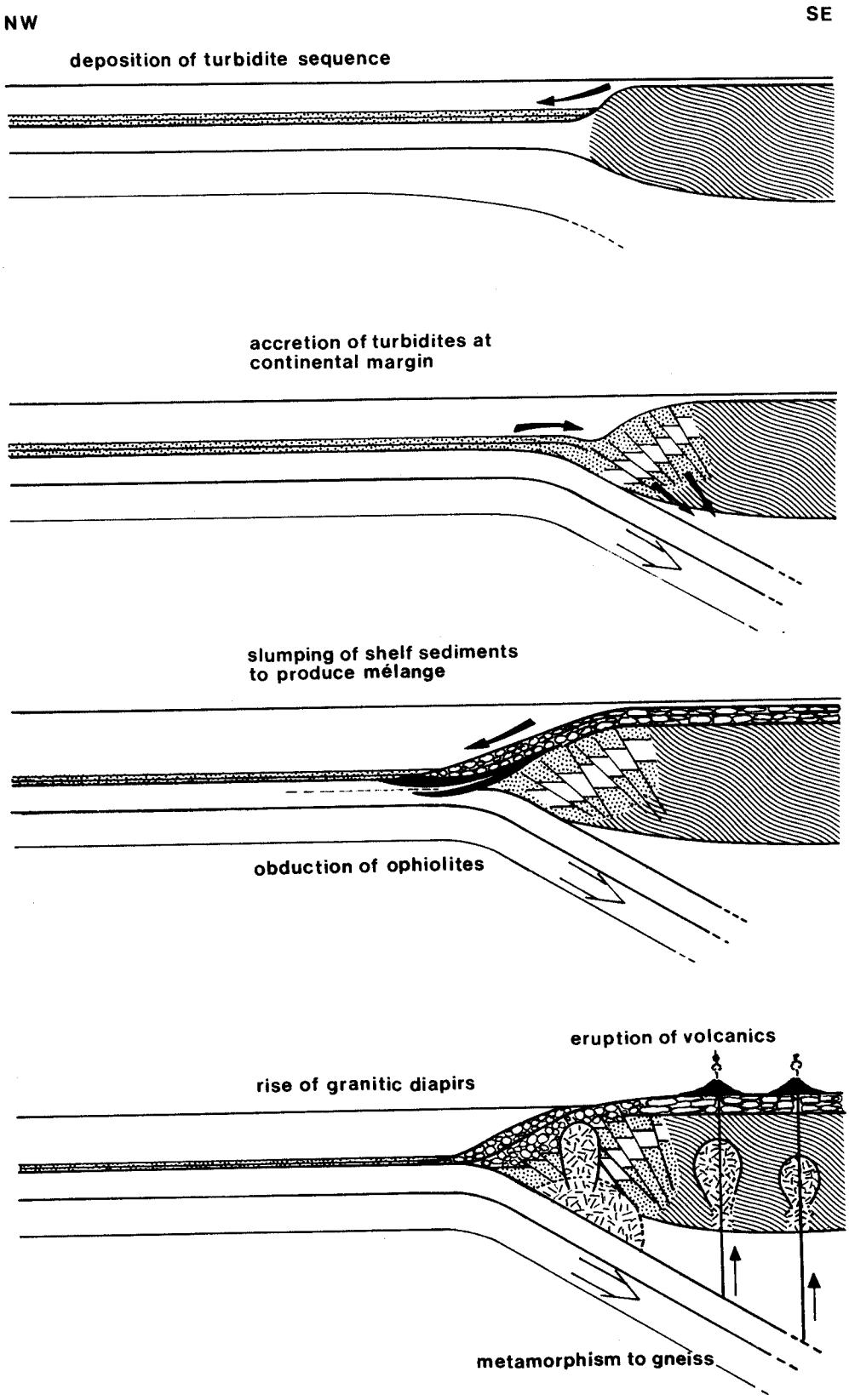

Figure 1 The Mona Complex: Single Subduction Model

between the schists and gneisses, and also pointed out that basic amphibolite gneiss outcrops adjacent to pillow lavas in the bedded group, whilst granitic gneiss outcrops adjacent to bedded quartzites - which is the relationship that would be expected if the gneisses were produced by in situ metamorphism of the bedded series. The gneisses were thus considered to be derived from the bedded series at the same time as the schists, but under conditions producing a higher metamorphic grade.

In a recent paper Barber and Max have reverted to proposing an Archaean age for the gneisses, as originally suggested by Greenly. The matter should have finally been resolved by radiometric dating of the gneisses, by Beckinsale and Thorpe, which indicated a Late Precambrian gneiss-forming event at 595Ma. It has been suggested since, however, that the age obtained may represent overprinting by the Late Precambrian metamorphic event on Archaean gneisses originally underlying the bedded succession!

Plate tectonic models for the Celtic orogeny in the Anglesey area fall into two main groups: those involving simple subduction at the southeast continental margin of Iapetus, and those involving sedimentation and subduction in a marginal basin separated from the main ocean by a landmass of Archaean gneisses.

According to the simple subduction model, as shown in Figure 1, sedimentation commenced at the southeast margin of Iapetus in Late Precambrian times with the deposition of deep water greywacke turbidites, quartzites and pelites, which formed the lower clastic group of the bedded succession. When subduction commenced these sediments were carried towards the continental margin and were emplaced as thrust slices above the descending oceanic plate. A shelf sequence of limestones, quartzites and mudstones was deposited on the continental margin as the Gwna Formation, and submarine sliding down the continental shelf towards the trench system produced the melange. This sliding evidently occurred whilst the sediments were only semi-lithified, and may have been initiated by earthquake shock waves from foci in the Benioff Zone during subduction.

An interesting feature of the Gwna Formation is the presence of considerable thicknesses of basalt pillow lavas, excellently exposed today at Newborough on Anglesey and near Nevin on the Lleyn. Wood (1974) has proposed that the pillow lavas, along with a group of basic and ultrabasic intrusions seen around the southern part of Holy Island and the adjacent mainland of Anglesey, represent ophiolites. These rocks originally formed as layers in the oceanic crust, being produced by igneous extrusion or intrusion at the mid-oceanic ridge. The lavas and intrusions now appear within the sedimentary sequence due to tectonic emplacement of thrust slices whilst subduction was occurring, a process known as obduction.

Geochemical evidence has been put forward by Thorpe in considering the origin of the pillow lavas and basic intrusions of the Mona Complex. Basalts and related basic intrusive rocks produced in recent geological times show a gradation in chemical composition from tholeiites, which are relatively rich in quartz but poor in alkalies, through calc-alkaline types to alkaline basalts, which are relatively rich in alkalies but correspondingly poor in silica. This gradation is thought to be the result of variations in temperature-pressure conditions at the sites where partial melting of mantle material occurred to generate the magmas. At shallow depth, as at a mid-ocean ridge system, low pressure conditions lead to production of a tholeiite melt. By contrast, magma generation deep in the mantle, along a subduction zone, under much higher pressure conditions results in a melt of alkaline composition. By analysing the Anglesey rocks, evidence should be obtained as to their tectonic origin either in a mid-ocean environment or at a subduction zone. Thorpe noted that, whilst results on the pillow lavas were somewhat inconclusive, the basic and ultrabasic intrusions of gabbro and serpentinite showed a clear tholeiite affinity. Further chemical evidence comes from the analysis of glaucophane schists considered to have been derived by metamorphism of the pillow lavas; these rocks again show a tholeiite affinity. The ophiolite origin of the basalts and basic intrusions is, therefore, supported.

As subduction continued through Late Precambrian times, metamorphism of the bedded succession took place above the subdution zone. Metamorphism was produced initially by shearing forces during underthrusting of segments of the sedimentary pile. Rocks of greenschist facies, and in some cases glaucophane schist facies, were produced with increasing pressure. At depth along the subduction zone, high temperatures resulting from frictional heating caused alteration of schists to gneiss, and ultimately a granitic melt formed. Diapiric bodies of magma could then rise through the overlying crustal rocks to be emplaced as high level intrusions or be erupted at the Earth's surface as lavas or pyroclastic sediments.

Three granite bodies in the area of the subduction zone have been identified as of Late Precambrian age: the Coedana Granite of Anglesey, the Sarn Granite of the Lleyn Peninsula and the Twt Hill Granite near Bangor. Shackleton has found a gradation between foliated, metamorphic, acid gneiss and the main body of the Sarn Granite, which is unfoliated and shows igneous contacts with country rock. Rhyolitic welded ignimbrites of supposed Late Precambrian or Early Cambrian age occur in Anglesey as the Fydlyn Group, and in Snowdonia as the Arvonian Formation. These would represent the eruptive equivalents of the granites.

The recent discovery by Muir of Cambrian fossils in the matrix of the Gwna Melange has intoduced some controversy over the paleogeography of the North Wales area during Lower Cambrian times. It had been assumed, following the work of Greenly, that all rocks of the Mona Complex were of strictly Precambrian age. In the Llanberis area, however, Wood (1974) has demonstrated a gradational upward progression from the Arvonian volcanics into grits of known Lower Cambrian age. The Anglesey region was therefore considered to have been elevated as the Irish Sea Landmass by Late Precambrian times, and subsequntly formed a source of clastic sediment for the Cambrian succession of the Welsh Basin. It now seems possible, however, that whilst the lowest grit members of the Cambrian were being deposited in a basin floored by downfaulted continental crust on the North Wales mainland, parts of Anglesey remained below sea level, with slumping of Gwna Formation shelf sediments continuing northwestwards down the continental slope into the Iapetus basin to produce melange units.

The subduction model detailed above must be modified if it is accepted that some, or all, of the gneisses of Anglesey and Lleyn represent Archaean basement, rather than parts of the Late Precambrian bedded succession metamorphosed in the subduction zone. Models have been proposed by various authors which involve the opening and closing of a back-arc basin. According to this model (shown in Figure 2) subduction of oceanic crust commenced beneath the North Wales area, on the southeast margin of Iapetus, in Late Precambrian times. At depth along the subduction zone, melting of the descending oceanic plate occurred and great volumes of basaltic melt were released upwards as a plume through the upper mantle. On reaching the base of the continental crust beneath North Wales the plume divided, and the divergent streams of the viscous melt caused rifting of the granitic crust and the opening of a back-arc basin. Eruption of basalt pillow lavas and intrusion of basic dykes as the basin opened gave a floor of new basaltic crust. With the ceasing of the main process of subduction at the margin of Iapetus, the basaltic floor of the back-arc basin cooled and itself began to subduct. This led to convergence of the rifted continental fragments and ultimate closure of the back-arc basin.

Following the back-arc basin model, the bedded succession of the Mona Complex represents sediments deposited on the floor of the basin itself, and the ophiolites represent basin floor obducted into the sedimentary succession during closure. The gneisses are therefore regarded as fragments of the continental crust originally bordering the back-arc basin.

Precambrian rocks outcrop in the north of Pembrokeshire, where they consist of a variety of intrusive and pyroclastic igneous types. These are considered to be of similar age to the intrusives and pyroclastics of Anglesey and Lleyn, and to be related to the same episode of Late Precambrian subduction of oceanic crust southeastwards from the back-arc basin or from Iapetus itself. Three

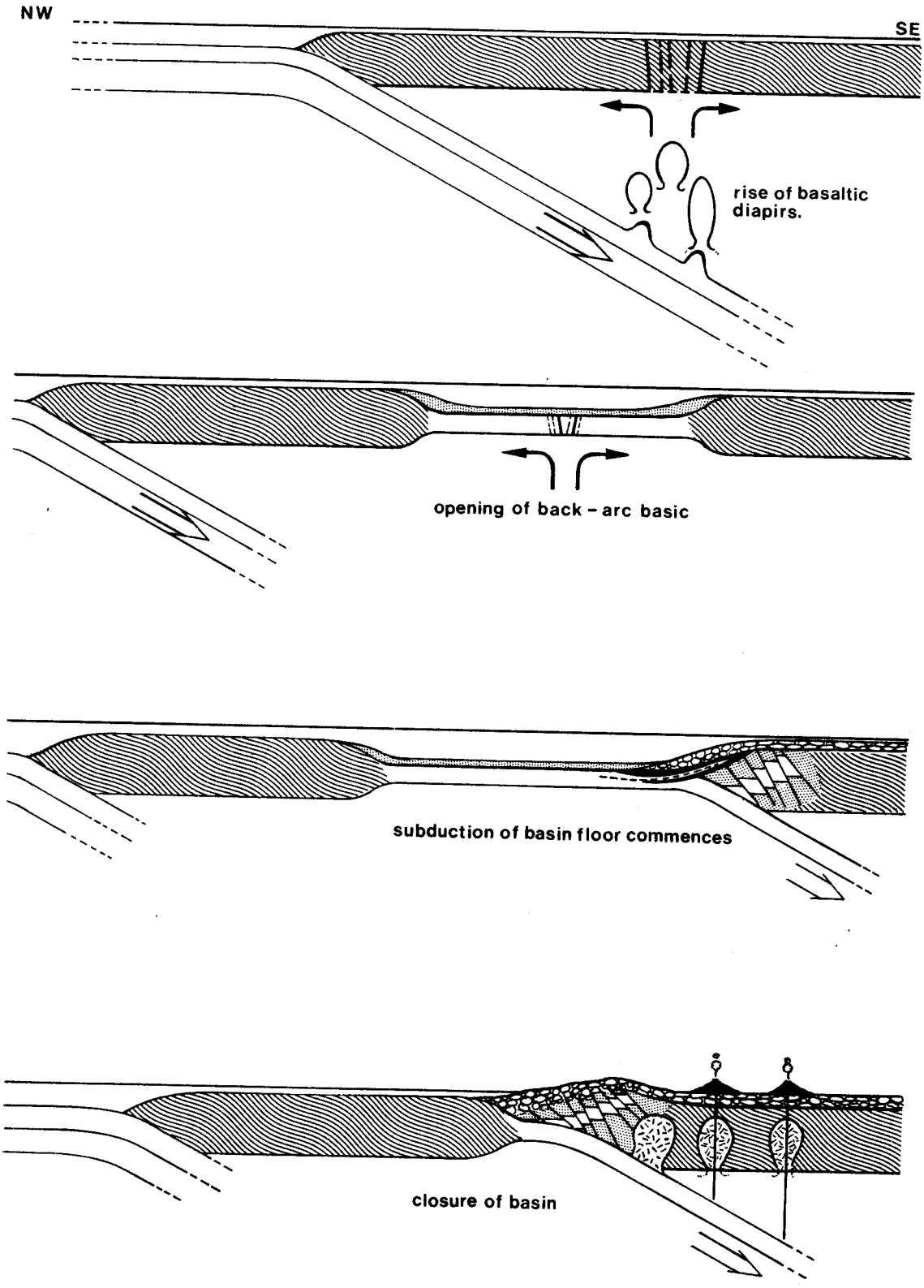

Figure 2 The Mona Complex: Back-arc Basin Model

groups of Precambrian rocks have been identified in Pembrokeshire. The Dimetian Formation consists primarily of granitic intrusions, and represents high level magma emplacement above the subduction zone, analagous to the Coedana and Sarn Granites. The Pebidian Formation consists primarily of rhyolitic ashes and other pyroclastic rocks analogous to the Arvonian volcanics of Snowdonia. The final group, the Johnson Series of dioritic intrusions, again consists of magma emplaced above the subduction zone. Thorpe notes that all the Pembrokeshire Precambrian rocks have a calc-alkaline affinity, characteristic of emplacement at a continental margin above an active subduction zone.

By Early Cambrian times subduction of oceanic crust beneath the Welsh area had ceased, and sedimentation continued through Cambrian times uninterrupted by volcanic activity. The Welsh Lower Palaeozoic sedimentary basin consisted of a subsiding fault trough developed within the continental foreland to the southeast of the Iapetus ocean, and it is presumed to be underlain by the Archaean basement rocks. The basin was bounded to the northwest by the Menai fault system, and to the southeast by the Church Stretton fault system. In a study of Cambrian palaeogeography, Crimes has shown that a variety of coarse grits, and finer silts and muds, were deposited in deep water by turbidity currents during the Lower and Middle Cambrian, but towards Late Cambrian times the basin shallowed and sands and muds were deposited near the wave base. The sediment was derived by erosion of the Irish Sea Landmass to the northwest or the Midland Platform to the southeast.

The important fault systems bordering the Welsh Basin lie parallel to the margin of the Iapetus ocean basin itself, and it is probable that they were developed in the Archaean basement at the time the initial tensional rifting produced the Iapetus basin, in Precambrian times. Subduction recommenced at the southeast margin of Iapetus at the very end of the Cambrian period, and probably continued through Ordovician and Silurian times until closure of the Iapetus basin was completed with the Caledonian orogeny.

The earliest phase of volcanicity in Wales associated with subduction was in Late Tremadoc times, when volcanic centres became active at Rhobell Fawr in the Harlech Dome and at Treffgarne in Pembrokeshire. Kokelaar has made a detailed study of the Rhobell Fawr centre, where erosion and faulting allow the study at the present day of the dissected volcanic cone and the well-developed sub-volcanic intrusion complex. The volcano is composed of gently inclined basalt lava flows radiating from the central vent zone, lying with marked angular unconformity on vertical or overturned Upper Cambrian sediments. The volcano was fed by a series of fissure-type magma conduits which are represented by vertical sheet intrusions of diorite and dolerite (see Figure 3).

Examination has shown that block faulting of the basement of the Harlech Dome occurred along a north-south line called the Rhobell Fracture immediately prior to the initiation of volcanicity, and the fracture zone then formed a direct route for magma to rise through the crust to the surface. The effect of the block faulting was to produce a monoclinal drape fold in the semi-lithified Upper Cambrian shale succession at the site where the volcanic centre developed.

The Rhobell Fawr volcano is of particular interest because part of the sub-volcanic diorite intrusion complex has an associated porphyry copper mineral deposit. This deposit, occurring around the village of Capel Hermon in the Coed y Brenin forest, was investigated in recent years by a mineral company and considered a viable economic prospect. The rocks affected by the mineralisation include both intrusions and shale country rocks, and show pronounced decomposition to secondary clay and mica minerals under the action of hydrothermal vapours. Copper is present, along with iron, in the form of disseminated crystals of the sulphide. Vein quartz is present on a limited scale and also carries sulphide minerals.

During the Arenig, Llanvirn and Llandeilo divisions of the Ordovician, volcanicity became widespread. A series of volcanic centres developed along the line of a deep fracture in the Archaean basement of the Welsh Basin from the Aran Mountains though Cadair Idris to Strumble Head

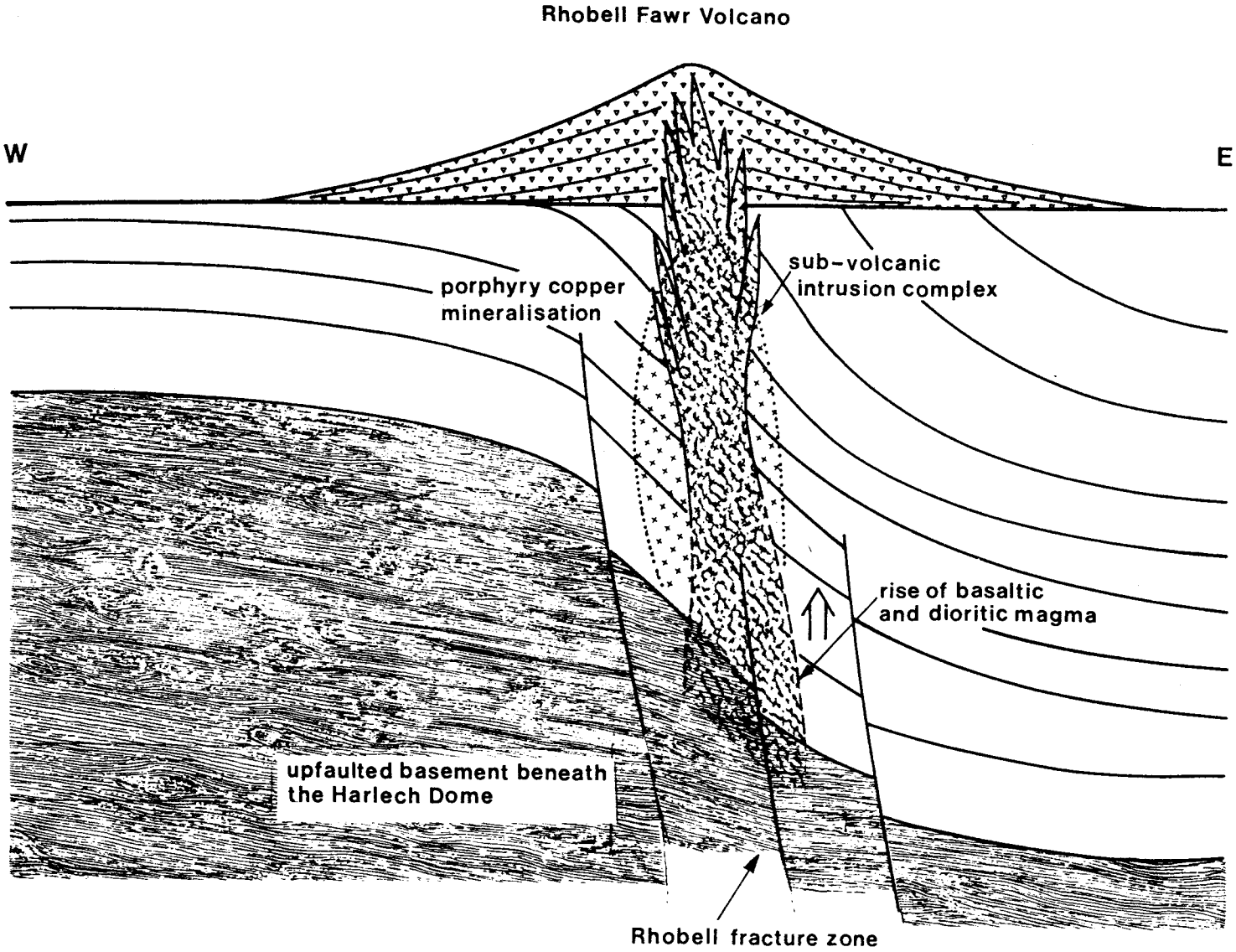

Figure 3 Structure of the Rhobell Fawr Volcanic Centre

in Pembrokeshire. This important fracture, the Bala Fault Zone, with its continuation across Cardigan Bay to the north coast of Pembrokeshire, provided an easy route for ascent of magma through the crust. A volcanic centre was also active during Llanvirn times at Builth Wells, and was similarly associated with the deep fracture system of the Church Stretton Fault Zone which formed the southeast margin of the Welsh Basin.

Many of the volcanic rocks occurring at the Lower Ordovician volcanic centres are basalt pillow lavas with spilitic alteration indicative of eruption in a submarine environment. Excellent examples occur at the summit of Cadair Idris and near Strumble Head lighthouse. Geochemical studies lead to the unexpected result that the basalts are tholeiites, rather than the calc-alkaline types which might be expected in a continetal margin environment above a subduction zone. The magma may have been generated by partial melting of the upper mantle at the base of the crust, where deep fractures could allow a reduction in confining pressure. This process differs from the normal mechanism of magma generation involving the partial melting of the descending oceanic plate by frictional heating deep in the mantle.

An examination of sub-volcanic intrusions associated with the Lower Ordovician basalt pillow lavas suggests that magma reached the sea floor along NE-SW trending vertical fissures in the fracture zone. Near Cadair Idris a sheet intrusion of dolerite outcropping on Mynydd y Gader probably represents a fissure vent for the series of lavas forming the summit of the mountain. This sheet is now inclined due to Caledonian folding, but would originally have been near vertical. A sill offshoot follows the bedding plane of the sedimentary sequence, and indicates lateral spreading of the magma at a level where it had reached lithostatic equilibrium with the confining rocks. In Pembrokeshire a series of near-vertical basic intrusions follow the same NE-SW trend and probably represent feeders for the Strumble Head volcanic series. The most impressive of the intrusions, the St. David's Head and Carn Llidi complexes, have been shown by Roach to be composed of numerous vertical gabbro and diorite sheets of varying mineralogy. This suggests repeated eruption from the same fissure system. As in the case of the pillow lavas, the intrusions show a tholeiitic composition.

By the Caradoc division of the Ordovician, volcanicity was no longer concentrated near the Bala Fault Zone, but had spread throughout Snowdonia. A notable change in magma type occurred, with granitic melts becoming dominant. At this time it is thought that widespread partial melting was taking place on the subducting oceanic plate as it descended into the mantle beneath Wales from a trench system in the Solway Firth area. Rising diapirs of basic magma reached the base of the continental crust beneath the Welsh Basin. When they came into contact with granitic rocks of relatively low melting temperature heat transfer resulted in the generation of granitic magma.

The physical processes involved in the upward movement of magma through the Earth's crust differ for basaltic and granitic melts. Basaltic melts have a high density and remain at deep crustal level until driven upwards to a volcanic vent by the action of steam vesiculating the magma. Intrusions below the basaltic volcanoes tend to be restricted to the vertical vents themselves and occasional sill offshoots of degassed magma. Granitic melts, however, are of lower density than much of the Earth's crust, and tend to move upwards to a high crustal level immediately after formation. A study of the geology of Snowdonia suggests that the area was underlain by a granitic magma substratum at shallow depth during Caradoc times, and that eruption of volcanics occurred from centres above the magma reservoir.

The edge of the Caradoc granitic magma chamber has been exposed at the surface at the present day on the northern edge of the Harlech Dome, as the Tan y Grisiau microgranite intrusion. This occurs at the stratigraphic level of the Upper Cambrian Tremadoc beds. The intrusion has a well-developed metamorphic aureole, which is unusual in showing tourmaline crystals deposited by hydrothermal vapours from the cooling granite. Bromley has identified tourmaline-bearing thermally metamorphosed sediments at various localities in Central Snowdonia, in the absence of out-

crops of intrusive bodies, so it is assumed that the Tan y Grisiau microgranite extends at shallow depth over much of the region.

It is likely that the majority of eruptions of granitic magma in Snowdonia during Caradoc times took place from volcanic centres situated along a line from Conwy to Nevin. A series of granitic bosses penetrating upwards into Ordovician strata represent volcanic necks; these include the Aberdrosgl, Nant Francon, Mynydd Mawr and Northern Lleyn intrusions. The intrusions may lie on a deep fracture zone penetrating the Archaean basement, and forming the faulted northwest margin of the Welsh Basin. This would provide a pathway for magma to reach the high level reservoir beneath Central Snowdonia and also a focus for volcanic vents above the magma chamber.

The majority of eruptive rocks of Caradoc age in Snowdonia are rhyolitic ignimbrites. These deposits were produced by the explosive discharge of clouds of hot magma froth down the sides of volcanic cones. The welding together of hot glass shards when the ignimbrite cloud came to rest is indicative of deposition on land. The accumulation of a great volume of acid magma in a high level reservoir beneath Snowdonia may have been responsible for the elevation of the sea floor in Late Ordovician times to produce sub-aerial conditions. It is thought that explosive eruptions of rhyolite froth could occur intermittently as vesiculation occurred during crystallisation of the melt.

Moving southwards from Central Snowdonia, it is noticed that a ring of pyroclastic rocks of Caradoc age also outcrop around the Harlech Dome, from the Moelwyns in the north, through the Arennigs and Arans, to Cadair Idris in the south. In a study of Ordovician palaeogeography, Ridgway has suggested that the acid volcanics around the Harlech Dome were erupted radially from a large volcanic cone in the central area of the Rhinog Mountains. It has also been suggested that the Harlech Dome may itself be a volcano-tectonic structure arched upwards by an underlying magma chamber during Ordovician times. If this is correct, a substantial volcanic vent system should penetrate the Cambrian strata in the central area of the Dome. A series of granitic intrusions does indeed occur south of Trawsfynydd reservoir, but is by no means adequate for supplying the volumes of ignimbrite seen in the surrounding volcanic mountains.

Structurally the Harlech Dome is not a simple anticlinal fold. Dips in the central area are very gentle and in irregular directions, whilst a narrow zone of very steeply dipping or vertical strata occurs on the eastern flank of the Dome between Ffestiniog and Dolgellau. Following work by Kokelaar, it is likely that the Harlech Dome is underlain by upfaulted Archaean basement, with steep dips at the Dome margins representing drape-folding of the Cambrian succession over the edges of the fault block. An analogy may be drawn with California at the present day, where intersecting sets of faults above an active subduction zone have divided the crust into roughly rectangular fault blocks.

Mapping of the Harlech Dome reveals a concentration of intrusions in zones along the eastern and southern margins of the Cambrian outcrop from Ffestiniog to Dolgellau, and then to Barmouth, as shown in Figure 4. These may represent magma which rose along the Bala and Rhobell fracture zones and was erupted from volcanic centres in Caradoc times. The majority of intrusions are of dioritic composition, but Cox has shown that on Cadair Idris gravity differentiation of a subvolcanic magma reservoir led to eruptions of rhyolitic melt from an original diorite magma.

It is interesting to note that a belt of Caledonian quartz-sulphide mineralisation with copper and gold exactly follows the fracture zones on the eastern and southern margins of the Harlech Dome around Dolgellau. It is likely that the Bala and Rhobell Fracture Zones remained active into Silurian times, providing a route for the ascent of mineralising vapours during the Caledonian hydrothermal event.

Volcanicity died out in Snowdonia and the Harlech Dome by Upper Ordovician times, but continued into the Silurian in Pembrokeshire with the eruption of the Skomer volcanic series. This is explained in a model by Phillips et al, who propose an oblique closure of the Iapetus basin. The

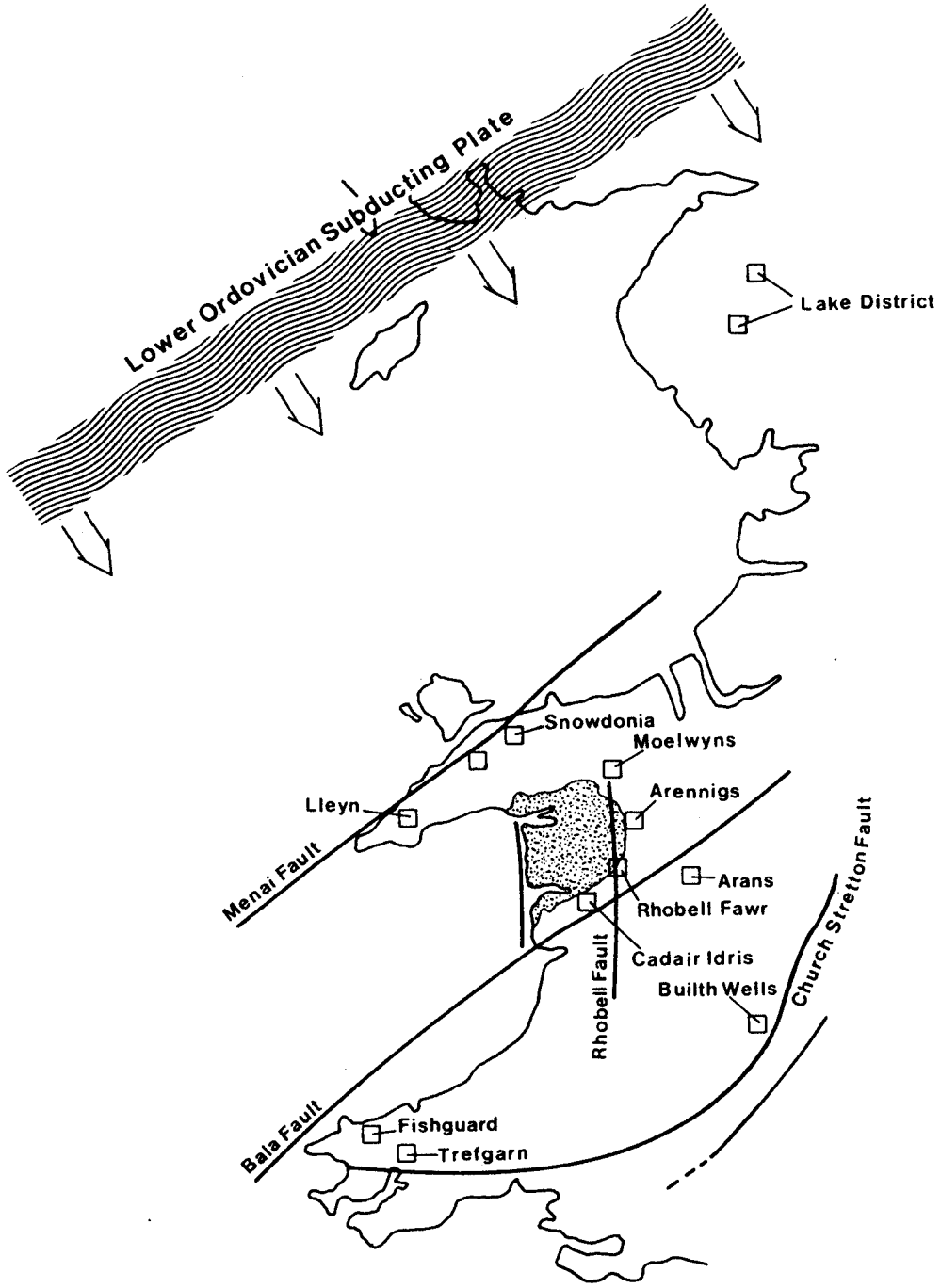

Figure 4 The Relationship between Ordovician Volcanic Centres and Deep Fracture Zones in the Welsh Basin

continental forelands first came together in the northeast during Late Ordovician times, and the point of convergence gradually migrated to the southwest during the Silurian period. This convergence meant that subduction and volcanicity ceased first in the Lake District and progressively later towards Pembrokeshire.

During convergence, marine sediments at the margins of the Iapetus basin were intensely deformed in the suture zone through the Southern Uplands of Scotland, but deformation became progressively less intense across the continental forelands. Caledonian folds in Snowdonia and the Harlech Dome are generally open and of large wavelength, although slaty cleavage is well developed in pelitic sediments throughout North Wales. Low grade regional metamorphic minerals such as chlorite and sericite are commonly developed in muddy sediments and basic igneous rocks in the region, giving the characteristic green colouration of much of the Lower Palaeozoic succession. Unexpectedly intense folding and thrusting of Silurian sediments in the Plynlimon area of central Wales has recently been shown by Wood (1981) to be the result of gravity sliding of semi-lithified material with the onset of Caledonian tectonic movements.

Major advances in our understanding of Precambrian and Lower Palaeozoic geology have been made since the introduction of plate tectonic theories. The main Iapetus Ocean expansion/contraction cycle is accepted as giving a convincing explanation of sedimentation, volcanicity and orogenesis in Wales. On a local scale, however, there are still a number of problems facing the geologist. The sequence of Late Precambrian events culminating in the Celtic orogeny is not fully understood, and further useful work could be carried out in determining the nature and distribution of Ordovician volcanic centres in Wales.

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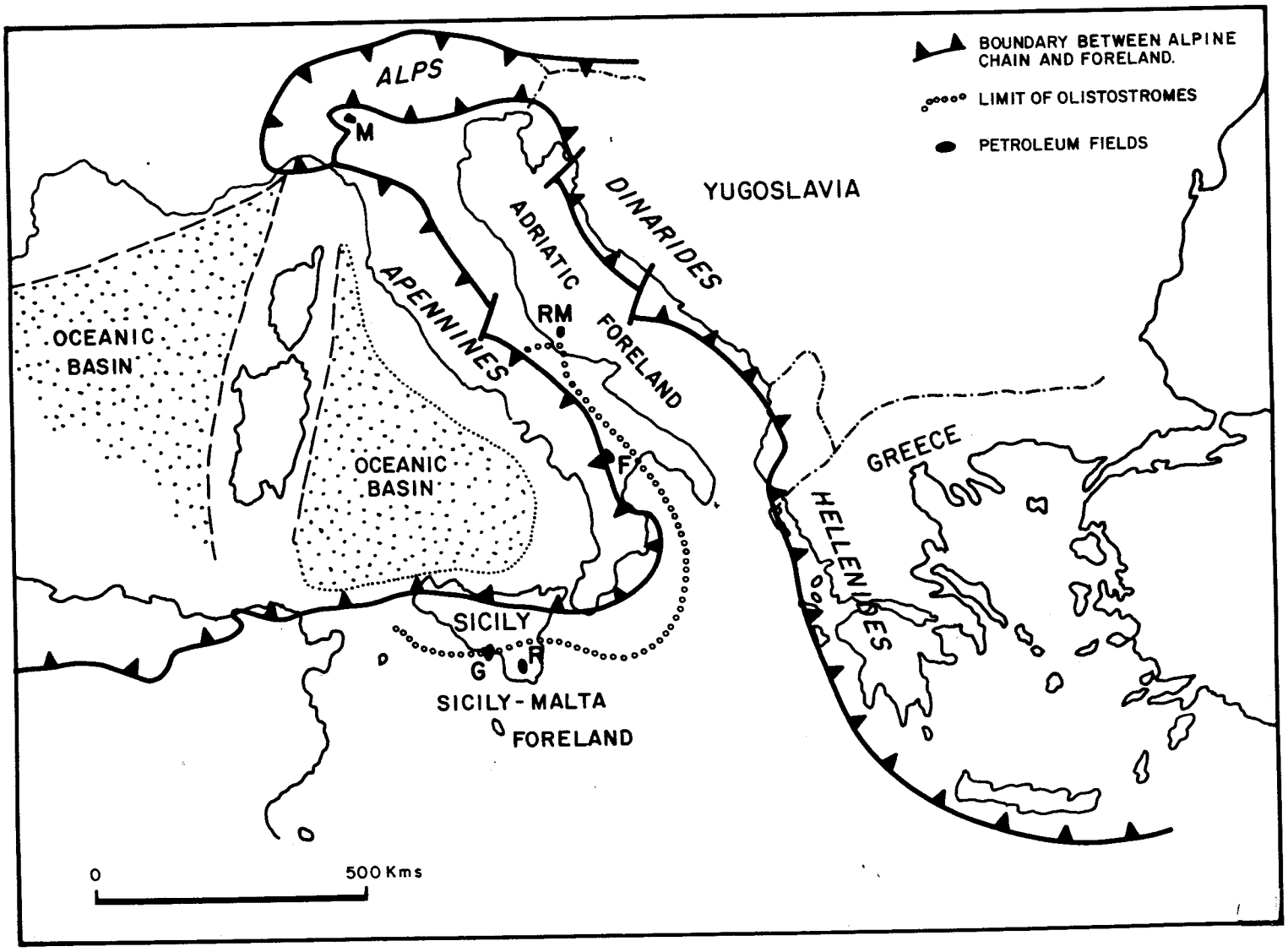

Figure 1 Tectonic framework of the Peri-Adriatic region, and the location of petroleum fields referred to in the text

F = Ferrandina, G = Gela, M = Malossa, R = Ragusa, RM = Rospo Mare

PETROLEUM PROSPECTING IN THE PERI-ADRIATIC REGION

Dennis Jackson

The substance of this paper was delivered at the Society's AGM in 1981 and, but for the fact that our Editor is hard up for material, it would have been condemned to obscurity. (*If you believe that you'll believe anything - Ed.*) The aim of the paper is to look at the kind of work, and the nature of the problems, that geologists encounter working in an exploration team of a major oil company in regions classified as 'New Ventures'.

New Ventures deals with areas of the world in which the company has no exploration activity at present. The Peri-Adriatic region, comprising Sicily, Italy, Yugoslavia and Greece, is one such area at present for Amoco. I make no attempt to present new data on this interesting region, but I will attempt to show why this petroleum province is as fascinating as it is geologically different from the North Sea province.

A geologist in New Ventures spends much of his/her time either studying undrilled basins/sub-basins or evaluating oil and gas prospects in specific areas related to exploration licences, and then makes appropriate recommendations. For reasons to do with stratigraphic seals, depth of burial with respect to the generation of oil and gas and, to a lesser extent, tectonic complexity of the onshore regions, most of the current exploration activity is concentrated in offshore areas, where seismic surveys can be done more quickly and cheaply, where thick Tertiary seals exist and where the geological structure is simpler. The same picture holds for offshore UK.

The Geological Framework

The structural framework of the Peri-Adriatic region is dominated by a sinuous mountain chain formed, during the Miocene, by the Alpine orogeny along the edge of the Adria microplate. The Alpine chain extends from Tunisia to Sicily before arching northwards through Italy - as the Apennines - and looping through the southern Alps and thence southeastwards through Yugoslavia and Greece as the Dinarides and Hellenides respectively (see Figure 1).

The other striking feature of the region is that this mountain chain has been thrust over the stable foreland of southern Sicily and the Adriatic. A consequence of this is that the Apennines and the Dinaride-Hellenide chain have opposite vergences (thrust slices in the allochthon tend to dip westwards in Italy and eastwards in Yugoslavia). In contrast to the structural complexity of the multiple nappe sheets of the allochthon, the foreland beneath what is now covered by the Adriatic is characterised by open folds and steep-angled faults.

When the Apenninic nappes are unravelled - a process called palinspastic reconstruction - and facies are restored to their relative geographic positions, a picture emerges of Mesozoic palaeogeography in which Adria had an array of long linear troughs containing thin deep-water sediments and 'ridges' of thick shallow-water carbonates. This picture held from the Triassic until the end of the Cretaceous. From an exploration viewpoint we would expect the troughs to contain the source rocks capable of generating oil and gas, whereas the reservoir rock such as reefs would tend to be found over the ridges.

An added complexity is the existence of chaotic masses of sediments in the Miocene, Pliocene and Quaternary of Sicily and Italy. These are called olistostromes and were formed as synsedimentary gravity slides in front of the rising Alpine fold belt.

Exploration Licenses

Exploration licenses vary greatly in size of area covered, ranging from 400 to 4000 km^2. As you might expect, the size of the licenses tends to vary inversely with the number of wells that have been drilled. In other words, as a basin becomes more intensively drilled the licenses tend to be smaller. The first phase in evaluating a prospect concerns the acquisition of geological and geophysical data. The geological data can come from published maps and papers about onshore geology, student theses, existing wells and pure rumour, which the industry refers to as scout data. The geophysical data is in the form of seismic lines and maps on specific stratigraphic horizons.

Serious difficulties arise, as happened in 1981 with Greece and Yugoslavia, when the holder of the licenses refuses client companies permission to buy or borrow actual seismic lines for interpretation and presentation back at head office. In such a situation client companies have to resort to pencil tracings. This is like asking someone to stake £12 million on the correct identification of a mineral using nothing more than a pencil sketch!

In 1981 several large licenses were offered by Greece and Yugoslavia in areas that are largely undrilled. These were termed 'ground floor' deals, and as such the terms are normally the best that can be expected (cf farmout deals). This is as it should be, because at this stage existing seismic data is rather sparse and traps are, therefore, ill-defined. For example, anticlinal folds may be located in the area, but proof of structural closure on all four sides may be lacking. That is why the first thing a company might do after acquiring such a license is to shoot a detailed grid of seismic lines over the promising leads.

A second way of acquiring whole or part interest in a license is via the farmout route. In 1981 many companies suffered serious cuts in their exploration budgets due to a fall-off in revenue as demand for petroleum and petroleum products dropped. One way of getting a well drilled on a license you own when the funds are not available is to farmout to another company. A common deal in such a situation is that the farminee contributes to the cost of the well on a 2 for 1 basis, eg if a 25% interest in the license is acquired the farminee will pay 50% of the well costs.

Geological Prospects

The first geological prerequisite for hydrocarbon accumulation is a reservoir. A reservoir is a rock with pores capable of holding gas or oil, which is also permeable enough to allow migration into the trap and withdrawal in economically profitable quantities. Now that we have the technology to drill 7-8 kilometres into the earth's crust one might think that the answer to dwindling reserves would be to go deeper. Unfortunately an inescapable fact of life is that porosity tends to decrease with depth of burial and increasing age. In other words preservation of pore spaces is depth, heat, pressure and time related. Research shows that a given sandstone with 25% porosity at a burial depth of 1000m will have no better that 5% porosity at 6000m. This fact is very important in exploration in the Adriatic, where Triassic sandstones lie at such depths (see Figure 2) and may, therefore, be rendered uneconomic. A great deal had been learnt in the past decade concerning the formation, preservation and destruction of porostiy during burial, but less is known concerning how we can predict rock properties ahead of the drill.

A second requirement for a petroleum trap is a seal above the reservoir. Not uncommonly we speak of seals and shales in the same breath. In the Adriatic, however, evaportic seals from the Triassic and Miocene, and dense, fine-grained, pelagic limestones from the Cretaceous, are the most common seals. The limestone tends, however, to be exceptionally brittle and, therefore, prone to leakage over folded structures.

A third requirement is a geometrical configuration which results in the hydrocarbons being unable to escape laterally. Structural closure on all sides is one way, being analogous to a domal reef body enclosed by overlying shale. Anticlinal traps in the Adriatic were formed by compressional tectonics and by salt diapirs. Often the two types of structure can be distinguished by their symmetry, or

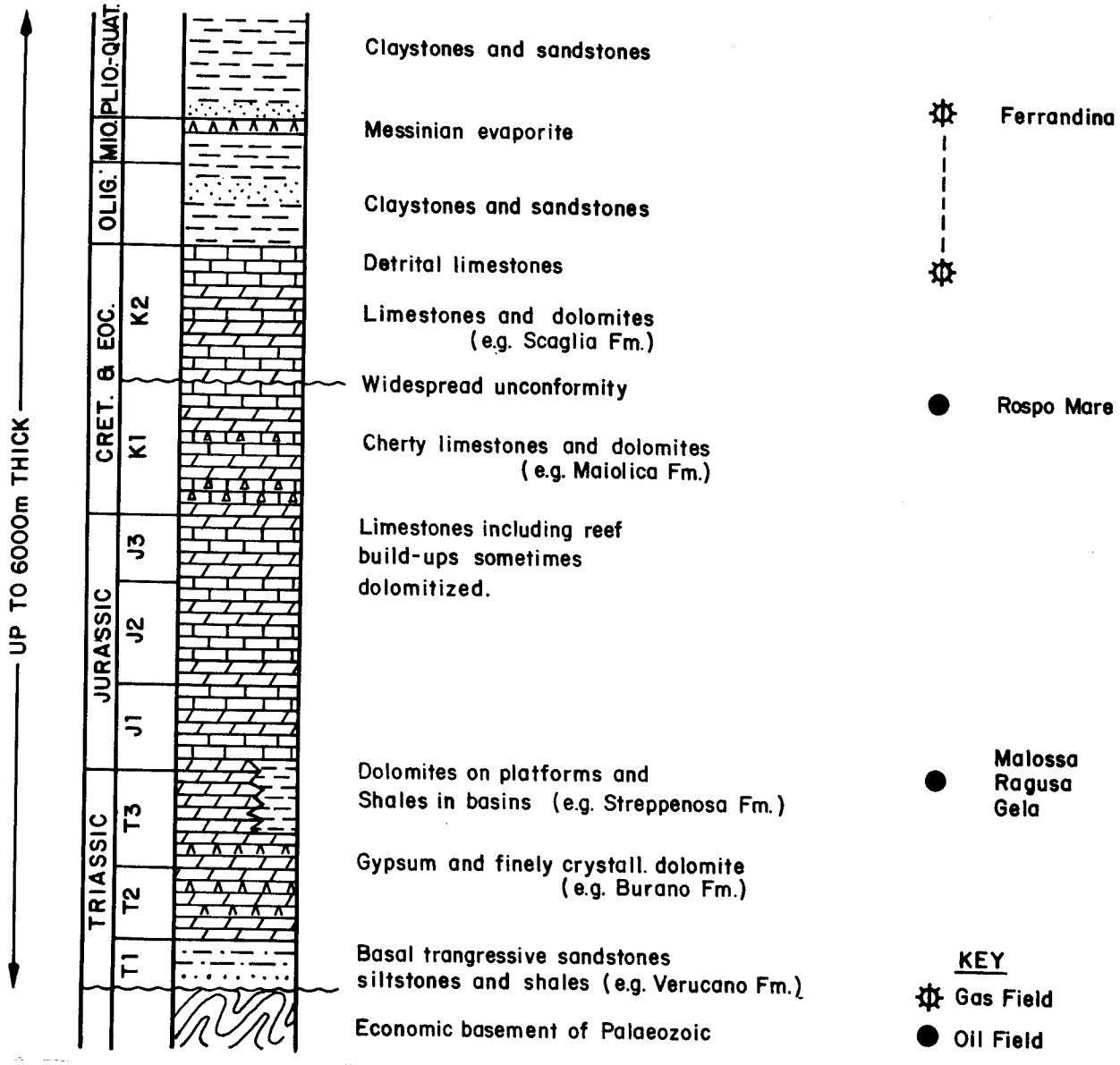

Figure 2 Generalised stratigraphic column for the Peri-Adriatic region, plotting the oil and gas fields referred to in the text against age

lack of it. When this is not possible the association of extensional faulting with salt doming is another criterion.

It is important to ascertain the precise time of origin of anticlinal traps because hydrocarbons will be trapped only if the trap existed when the hydrocarbons migrated into the reservoir beds. It's a 'locking the stable door after the horse has bolted' type situation! I can imagine you are now saying "OK, I can work out the age of the folding, but how do I handle migration history?". Well you will have to come to the 1982 Conference if you want the answer to that.

Before leaving structural considerations, it must be said that, unlike the North Sea, the Peri-Adriatic region and the Aegean Sea have been

subjected to very recent faulting and salt movement. Indeed, examples are known where faults form escarpments on the sea floor and salt doming has arched the sea bottom. Such movements may have weakened seals and caused leakage of hydrocarbons (especially gas) from Late Mesozoic-Tertiary reservoirs.

A fourth prerequisite is a source rock for oil and gas. Although it is probably true to say that nearly all of the world's oil and gas discovered so far was found prior to our knowing much about the origin and migration of the stuff, it is now becoming increasingly common to consider this aspect as part of the evaluation process. The reason for this is that, in recent years, industry has acquired convincing geochemical evidence that the conversion of organic matter in a source rock from kerogen to petroleum is largely a time/temperature dependent process. Something like 3000m of burial is needed to promote the generation of petroleum, though this can be reduced if the formation process involves long range migration.

The Mediterranean seems not to be well endowed with source rocks. The best known is the Streppenosa Formation of Upper Triassic-Liassic age in Sicily. These source rocks were deposited in an euxinic basin between Sicily and Malta and are the source of the oil in the Ragusa and Gela oilfields. Apart from this correlation, the source of the oil in Italian fields is veiled in mystery, giving poignance to the saying 'Oil is where you find it'.

Economic Evaluation

The final phase in the evaluation of a prospect involves estimates of recoverable reserves in a structure, the number of wells required to exploit those reserves, and drilling and production costs. When these calculations have been completed the economists can provide an indication of the level of profitability which can be expected from drilling the prospect. This figure is referred to as the PI.

Finally, management will consier tax laws and royalities, and the political complexion of the government of the day. Italy has favourable taxation and is considered politically safe. Greece is considered likewise - but will it continue to encourage exploration by foreigners? Yugoslavia is a communist state which has recently encouraged foreign investment and the same thing is happening in Roumania and China. As mentioned earlier, Yugoslavia and Greece both offered large licences to the industry, but the outcome must have been a disappointment to those governments. Very few bids were possible beause the contracts called for very large expenditures in regions with unknown petroleum prospects.

Petroleum Discoveries

In terms of European drilling activity the Peri-Adriatic was the second most active province, after the North Sea, during 1981. But the history of exploration goes back almost to the beginning of the Age of Petroleum. The first commercial oil discovery was made in 1892, about 60km south of Milan. Up until the 1960s the Italian state company AGIP was responsible for most of Italy's drilling activity. Following the enactment of the new hydrocarbon laws in 1967, foreign companies entered the search, and today there are 47 foreign companies involved in the Italian sector, with three in the Yugoslavian sector.

Since the end of World War II 175 oil and gas fields have been discovered in the Peri-Adriatic, of which 42% are offshore. Known reserves are estimated to be 3.5×10^9 barrels of oil equivalent, one tenth that of the North Sea. This can be explained by the fact that the Peri-Adriatic contains no giant fields. The largest oil field is at Rospo Mare (see Figure 1), with reserves of 600×10^6 barrels, whilst the largest North Sea oil field at Statfjord has 5500×10^6 barrels. The largest gas field is Ferrandina (see Figure 1), with original reserves of 20×10^9 m^3, which should be compared with the 90×10^{12} m^3 found at Groningen. In conclusion, favourable tax laws in Italy and Greece, together with the fact that Italy, Greece and Yugoslavia are between 70 and 90% dependent on imported oil, should ensure a high level of interest in this region for the foreseeable future.

THE IRON ORES OF THE FOREST OF DEAN

Clive Roberts

Although iron ore is not at present being mined on a large scale in the Forest of Dean, there is a great history of mining within the area. Workings have been proven to date back to Roman times, and they may have existed before then. But is was not until the 19th century need for iron that the mining industry really blossomed.

The total production of iron ore within the Forest between 1861 and 1925 was almost 4 million tons, peaking at about 200 000 tons per annum in 1871 and falling off to less than 1000 tons by 1925. The two World Wars saw brief increases in production, but it was the decline in demand which ran down the Forest's industry and, although there are some indicated reserves present, economics and a relatively poor grade of ore will inhibit future operations. The maximum amount of metallic iron obtained from the ore has been recorded as 45%, the average being around 30%.

The purpose of this article is not to describe fully the development of the industry, but to outline the occurrence of iron ore and, perhaps, to stimulate the interest of those who intend to visit a beautiful area, which holds many a delight for the geologist.

The Forest of Dean can be found on the IGS Monmouth sheet (No. 233 in the 1:50 000 series), as students of S23- will already know. The area is a distinct saucer-shaped syncline basically formed from Devonian and Carboniferous rocks. The area contains two major unconformities. Trotter describes two main periods of folding, faulting and denudation - an intra-Carboniferous period and a pre-Triassic period (Hercynian).

The most important strata containing iron ore are undoubtedly found within the Carboniferous Limestone Series, which preceded the Upper Coal Measures. In particular, the bulk of the ore is contained within the Crease and Whitehead Limestones, both of which suffered subsequent dolomitisation. They outcrop along the eastern and western sides of the syncline, the dip being much steeper on the eastern flank, and it is along these outcrop strips that mining operations were concentrated. At the base of the Carboniferous Limestone Series are the Lower Limestone Shales and Lower Dolomite, which are functionally impervious, so water drainage proved to be difficult for the deeper pits.

The iron ore in the Forest of Dean contains ferric hydroxides (in the form of geothite, limnite, etc) but is chiefly composed of hydrated ferric oxide and is thus given the overall term of haematite. A distinction can be made between brown and red haematite, confirmed by their different streaks, but this distinction is often obscure and is economically unimportant.

The main types of ore found are:

- massive or stalactitic haematite, containing virtually no gangue minerals. This is the purest form of ore. The old miners called this 'pipey ore' where it was thoroughly stalactitic and 'smith ore' where it tended to break down into a fine gravelly powder, but on the whole it was simply termed 'brush ore'
- brush ore with large amounts of gangue minerals, mostly calcite and dolomite. This was called 'bastard ore' by the miners, and was often traversed by slender, discontinuous, 'fingers' of pure brown haematite
- highly ferriferous dolomite, which grades from highly compacted to fairly friable, and contains on average 35% haematite

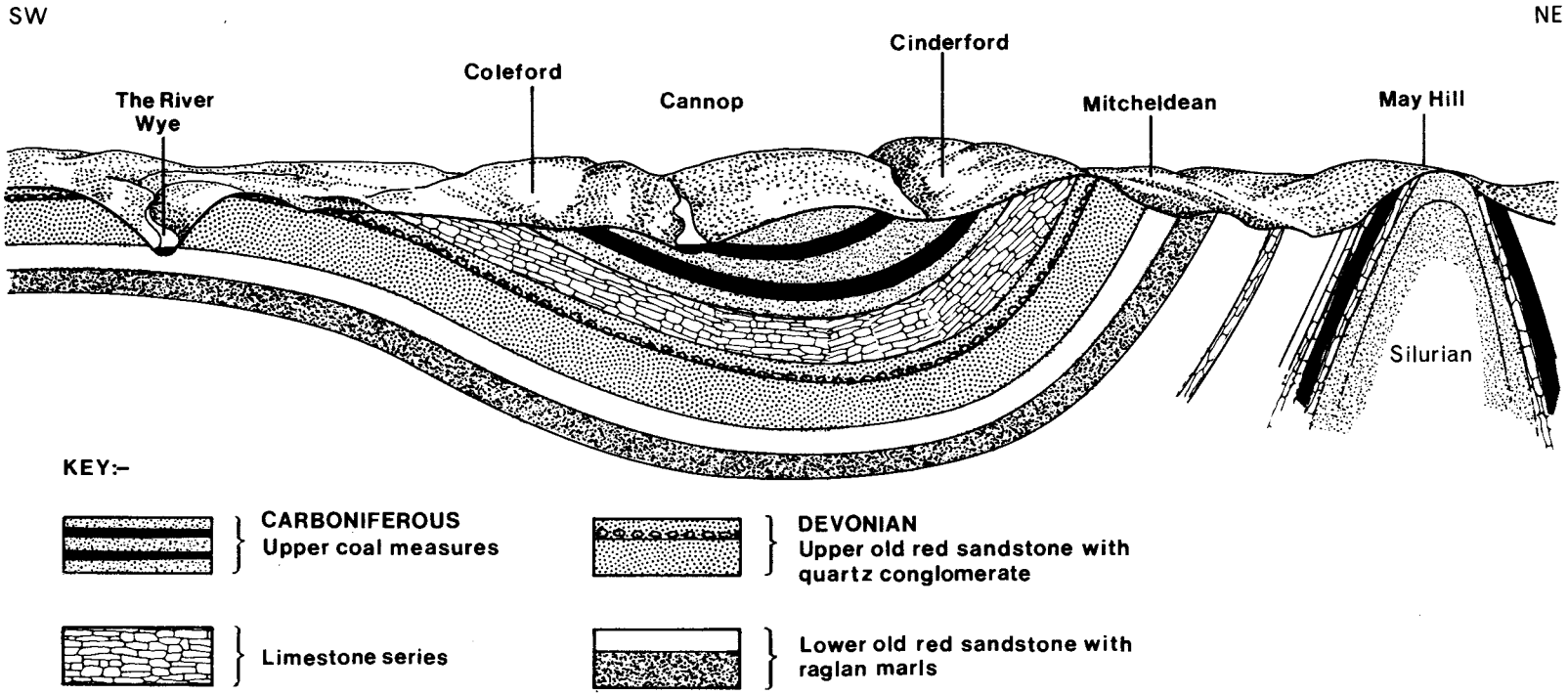

Figure 1 Block Diagram of the Forest of Dean

- ochre - red, yellow, brown and purple. These are broadly alteration products, red ochre greatly predominating. It is used mainly for dyes and paints. Where the concentration was high enough ochres were mined independently of the haematites, low grade ochre being called 'spurt' and high quality ochre being called 'colour'
- 'clod', or 'blue clod', was a rather rare ore present as an economic proposition in only one mine, Tufts Top Level. It is purple-red to blue in colour, wet and clayey in its natural state, and very easily kneaded. It did, however, contain up to 75% ferric oxide, so was a good potential for metallic iron. It was, incidently, very much regarded as a hindrance rather than an ore.

There are opposing theories on the origin of haematites, but it is generally agreed that the haematites were deposited by iron-bearing solutions as they descended into the Carboniferous rocks during the Triassic. This theory seems to be supported by the fact that the ores do not penetrate to any great depth in the strata, rarely getting more than 300m down dip, and also by the fact that some ore is found within the Upper Coal Measures, impervious layers presumably preventing the solutions from reaching the lower Carboniferous beds.

Sibley states that the ore was deposited from solutions which originated in Triassic rocks, but Jones favours destruction of the Coal Measures releasing pyrites which, on oxidation, gave rise to acidic iron-bearing solutions. Clearly the factors which allowed the deposition of the ores are the susceptibility of the measures to permeation by the solutions and the inclination of the units. The ores occur in irregular-shaped masses mainly formed by 'subsequent' metasomatic replacement of limestone and dolomite, fissure-filling and cavity-filling in general playing so small a part as to be practically negligible.

Mining in the Forest

The Romans confined their operations to surface outcrops, and rarely worked to a depth of more than 30m, probably because of drainage problems. Thus the scars of their workings are to be found in the outcrops of the ore around the perimeter of the Forest. These scars are called 'scowles' and often resemble giant trenches carved out of the rocks.

Perhaps the finest example is the Devil's Chapel, ½ mile southsoutheast of Bream Church, where a water mark is believed by some authorities to demonstrate the limits of Roman workings, although subsequent excavations have been undertaken. The Romans smelted their ore within the Forest, the nearby town of Cinderford deriving its name from where the Romans had bridged a shallow ford with waste slag.

Of course, not all scowles were created by the Romans and, although some are extensions of Roman excavations, many scowles are of a much more recent age These abound in areas called 'Meands' (from which the word 'mine' is derived). A fine modern scowle can be seen at Lining Wood Meand, near Mitcheldean.

Whatever the age of the scowles, good specimens of iron ore and associated minerals await the keen eyes of those who are prepared to look, especially in the more remote areas.

Up to the year 1800 iron ore was primarily won by the Free Miners of the Forest, who held special, obscure, rights to mine in the area. Some of these rights are still claimed today. Blast furnaces were present from an early date, the earliest recorded one being at Soudley in 1565. After 1800 larger concerns became established, and so there was a need to partition off sections of land. The responsibility for this fell to the Gaveller, an officer of the Crown who divided the Forest into distinct areas on the surface, which were called 'Gales'.

Shallow mines, which followed the gentler dips and used hand-carts to remove the ore, were termed 'land pits', and deeper mines which needed shafts to extract the ore were called 'deep pits'. There were upwards of fifty pits being worked in the Forest at the peak of production, two of which I will take as examples.

Clearwell Caves is a well-known local tourist attraction, being the site of the former British Land Pit. It was worked from 1855 to 1878, with a brief resurrection from 1902 to 1920. It falls within the Clearwell Gale. The caves are located ½ mile north of Clearwell village and are owned by Mr. Wright, who gives tours around the caves for a modest fee. It is well worth a visit, if only to get a feel of mining methods and to view the many artefacts which have been preserved from neighbouring pits. Near to the main adit there are some opencast excavations which include a nice exposure of where the iron ore has invaded the smooth red dolomites at the base of the Whitehead Limestone. Brecciation, pseudo-brecciation and recrystallisation are also well displayed here.

Old Ham Pit is the place for the more adventurous who would like a more leisurely look at an iron mine. It forms part of a very interesting complex within the Old Ham Gale. It was worked from 1846 to 1900 and connects up with the neighbouring gales of Clearwell, Lambsquay, Old Sling Pit and New Dun Pit. Thus a vast underground system of passageways was created, estimated at well over 10 miles in length. It is not too difficult to get lost here - as the Severnside Branch will tell you, we have at more than one point!

The ore was removed via shafts. The Old Ham Gale only supported one shaft as it was a relatively disappointing source of ore, but the miners gained access via a number of outcrop-holes, some natural, some modified. Later operations concentrated on the fairly good quality yellow and red ochres found in the mine at lower levels. Basically the miners did not follow an organised method of extraction but excavated wherever they could find the ore. There were, however, several levels with railways that supplied the main shaft, and thus took the ore to the surface.

The most accesssible entrance to Old Ham Pit occurs in the outcropping of the Whitehead Limestone located beneath a tree (honest!) in a field a mile north of Clearwell village. Prior permission needs to be obtained from Mr. Wright of Clearwell, and it is advisable to take a guide familiar with the caves with you.

The rocks in Old Ham Pit strike approximately N-S and dip roughly 15°E so, not unnaturally, the mine progresses in an easterly direction. On dropping down through the entrance a number of alternative routes are encountered, some of which are obscure, and a bit hairy. The most popular route winds its way around the collapsed floor, where the lower levels can be seen, and descends to Pit Bottom some 70m below the surface. On the way down there are a number of geologically and archaeologically interesting items to see.

Churn is the local name for any chamber, large or small, occurring in the mine. Some are probably natural, but most are the result of ore extraction. A few of the larger churns have a thin veneer of soot, demonstrating the ancient method of extraction. Basically great fires were set up in the churns to heat the iron ore and host rock before dowsing the whole area in water to crack the rock. What iron ore had not crumbled to the floor could then easily be loosened with a pick. Those miners who survived this precarious action were then able to load the ore into waiting carts.

The passageways in the mine are either natural or the result of excavation, the ways sometimes following bedding planes and joints in the host rocks. At various points within the mine fine examples of stone-walling can be seen, for which the miners were not paid. The purpose of these walls was to provide an area in which unwanted rock, called 'deads', could be dumped, creating an excellent support for the sometimes unstable roof. Incidently, the miners were only paid for the ore they removed, but this did not stop them from being fairly tidy in their mining activities. Where access was required from another part of the mine, or where a level was needed, they blasted their way through barren rock with the help of explosives. This was called 'chemical persuasion', and numerous shot-holes in Old Ham testify to its use. Most of these man-made tunnels contained railways, the best example being that at Railway Churn. A recent stretch of rediscovered passageway there contained a lump of foaming gelignite - so beware!

The boundaries of the iron ore tend to be irregular and ill-defined, but there are several phenomena to note. The deposition of the brush ore frequently shows a lenticular shape, parallel or sub-parallel to the limestone bedding planes. Such lenses are called 'vugs'. Many vugs hold secondary calcite and dolomite crystals. At a few locations in Old Ham veins of ore can be seen to have formed in varying sizes of joint-fissures, resulting in dip-joint veins called 'joints' by the miners. These are usually accompanied by anastomising stringers of ore, larger structures being called 'leads', because they lead to larger bodies of ore when followed. In the uncommon event of brush ore completely invading a bedding plane, the ore crystals can be seen to lie perpendicular to the boundaries of the bedding planes. Ochre is mostly found in obscure pockets without obvious bedding.

The Forest of Dean limestones and dolomites often contain shreds and patches of clay, purple/green or green in colour. In the Whitehead Limestone this clay characteristically develops into bands, with or without nodules of limestone or dolomite. As one descends through Old Ham these clays become extremely obvious. The limestone is also clearly interbedded in places with sands, oolites, marls and calcareous grits.

Since the cessation of operations in Old Ham natural cave phenomena have had a chance to develop more noticeably, the calcite formations sometimes being stained yellow and brown. Stalactites and stalagmites abound in almost all passageways, albeit in their infancy. Some walls are veneered by calcite flows, curtain formations being rarer, and even pure white calcite crystals can be observed in a few undisturbed pools. Tufa marks are present at very low levels in the mine, where the natural Forest water table can also be reached. The height of the water table is much lower in the Autumn, but the lower levels of the mine are constantly flooded, and this makes one ponder on the problems the old miners must have had with drainage.

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The Dinosaurs of Swanage

Jo Thomas

While digging the footings for a bungalow in the floor of an old quarry in Townsend Road, Swanage, David Selby recognised some dinosaur footprints. He informed the Dorset County Museum in Dorchester, and a team led by Assistant Curator Paul Ensom have since excavated an area about 4m by 13m. Volunteers with various skills have scraped and brushed, surveyed and drawn to scale, made plaster casts and finally lifted just one layer of the limestone. The team included geologists, archaeologists, biologists, surveyors and, finally, Borstal boys and prisoners from Dorchester jail (who thought all the stone-breaking stuff was for the films!). Such is Mr. Ensom's enthusiasm that I reckon we'd have had the top off Swanage in no time if it weren't for the houses in the way!

There are four beds with footprints, in a total of twenty identifiable beds within some 80cms (yes, centimetres) of micritic limestone and marl. In each case the prints have been covered by a bed of soft marl a few millimetres thick. In order to uncover the prints we cleaned the beds with trowels and hand-brushes, as in archaeological

digs, and so were able to find not only the footprints but also surface markings. These surface markings, which may indicate water current directions, are distinctive to each bed. Several beds showed suncracks, the size and shape of which were also characteristic of a particular bed, ranging in shape from 19cm squares to 5cm polygonals. One surface appeared 'bubbly' - perhaps it was burrowed from above by a small creature.

The fossil content of the beds also differed. Ostracods were present throughout, but the number of corbulids varied according to the bed. A few beds consisted largely of shell debris, identifiable (to me, anyway) only as bivalves. The ostracods suggest brackish water: the thin beds suggest rapidly changing conditions: mudcasts in some beds suggest that the current was occasionally strong enough to rip up fairly solid sediment: and the frequent suncracks suggest periods of drying out in a hot climate. Conclusions remain Mr. Ensom's prerogative!

Two fragments of an upper bed showed groups of megalosaurus and iguanodon footprints. One group of footprints has since been sold. The other, with 19 prints on one slab, will be built into the retaining wall. The main bed, showing three distinct trails, and a group of six trails, has been donated to Dorset County Museum and will be on display there as soon as it can be pieced together again and mounted. The lifting process proved how fragile the beds are, never being more than 2cms thick. Further prints have been found in two lower beds, which are being uncovered as the main layer is lifted.

There is one iguanodon trail on the main bed which takes a curved path across the site. The remainder of the footprints on the main bed come from megalosaurus - a meat eater. Both dinosaurs walked on two legs, holding their front limbs in the air and usually holding their tails level with their bodies. One megalosaurus, however, seems to have had his tail touching the ground as there is a thin line running through the trail of footprints. He seems to have been negotiating several 'puddles' in the soft mud, and to have landed on two feet after jumping over one.

There are several 'puddles', depressions filled with a finer sediment, showing a 'cliff' line on the southern edge, which suggests the prevailing wind was from the north. The relationship of the footprints to these depressions and the suncracks should enable Mr. Ensom to work out the relative timings of the dinosaurs' movements.

The Purbeck quarrymen inform us that the quarry was in the Laneing Vein: thus the footprint beds are below the Laneing Vein. By reference to Durlston Bay and Suttles Quarry (the nearest working quarry, about a mile away) I place the Townsend Road Beds between the Red Rag and the Laneing Vein, well above the Cinder Bed. The relevant beds are only exposed at low tide at Durlston, and do not appear on Clement's section. The Townsend Road footprints are in a higher bed, of a different character, to those noted in a roach above the Cinder Bed at Worbarrow (see the Worbarrow field trip report). There Ian West (in preparation) describes the deposit as a shell mush, acting like snow. At Townsend Road the micrite has very few shells, and must have been a smooth, 'squidgy' mud.

Further work at Townsend Road, Durlston, Worbarrow and the Purbeck quarries will be necessary before all the information can be assessed, and Mr. Ensom's paper on the subject will be published in the *Proceedings* of the Dorset Natural History and Archaeological Society, hopefully this year. I hope my personal notes on what has happened so far will whet your appetite to follow the whole story when it is published.

GEOLOGICAL CONSERVATION AT VALLIS VALE

Marion Gray

That geological sites need caring for was first brought home to me about two years after the opening of the Severn Bridge. Previously the Severn currents scoured the base of Aust Cliff, keeping it clear along its whole length. Now the current pattern has changed, parts of the foreshore are aggrading and the cliff has become heavily vegetated at its western end. The classic textbook faulting is no longer obvious. During this visit it was mooted that 'something ought to be done about it', but nothing was. When I found myself organiser of the West Country Branch I realised that here was an opportunity to do something about which I felt strongly. When I put the idea to the members of the time most of the 22 were prepared, in principle, to work for geological conservation.

Great! But where to begin. These sites all belong to someone, but who to? Was there no organisation that could offer advice? Apparently not. It was a question of following any and every vague path that might lead somewhere. Actually the Geological Conservation Review Unit of the Nature Conservancy Council had just come into being and was finding its feet about this time. Eventually our paths crossed, and Dr. Bill Wimbledon was able to offer an opportunity at Vallis Vale. This was further than we would have liked to travel, but the work needed doing and so we accepted.

By this time only 14 of our original members were left, and of these five turned up at our first exploratory meeting. Three, including myself, were geriatrics. The other two, seeing the site so well vegetated, felt they couldn't destroy it in the name of conservation. Useless to point out that it was only a relatively minute part of the area, and that in this instance clearing was justified. We had to respect their attitude and so lose two pairs of hands.

JCBs had removed the enormous amount of material tipped against the cliff face, but ledges needed hand clearing. The terrace, an unconformity surface, supported an immature woodland. We had a path only 2-3 feet wide to work from above a cliff the height of which was measured bodily by more than one of us. We were all completely clueless as to where to start, so just began hacking away.

Our second meeting was in monsoon conditions in December, which rather dampened the enthusiasm of two further recruits. I was now feeling rather apprehensive as to whether the work force would ever really materialise, and roped in two friends of mine. These two, plus our two other geriatrics, myself and Bill Wimbledon were our nucleus.

Our third meeting in January 1980 proved the turning point. Three more OUGS members plus two geologists from Bristol Museum joined us. The weather was an unbelievable heat wave! More importantly, the word was spreading. By June we were joined by Eileen Batten and other members of the South West Branch and Paul Clasby came up from Hampshire with a party from the Southampton Field Club.

After that Branch members turned up as and when they could whilst professional geologists came to see what was going on and stayed to help. Members from local geological societies were now a regular part of the team. Avon Wildlife Trust, the newly formed county Trust, sent a party, two of whom were OU students.

Altogether 46 people have taken part, and of these only eight have not returned after the first visit. We work hard, each according to his/her ability. There is a need for the strong arm and also for the more delicate touch. Some use pick and shovel where necessary - others work with trowel, hand

broom or secateurs. We have a lot of fun in a beautiful, peaceful setting. For those so inclined we have honorary membership of a nearby licenced club.

There has been the odd occasion when we were down to three in number, but the following meeting usually makes up for this. Last year the weather was a little unkind. At the end of April the area awakened to two feet of snow and we couldn't leave the house. Paul Clasby, travelling from Hampshire, did most of the journey in brilliant weather before running into the arctic conditions. It would take another article, written by Paul, to describe his hilarious vicissitudes, but he made it. Frank Critchley turned up in May and considered himself very noble to be the only one to face the deluge. Later I crassly disillusioned him by telling him he had made the wrong Sunday! I went on the right Sunday, albeit very late, and was the only one in the pouring rain. Such nobility, I thought, until I later found one dear soul had put in three hours work and left before I arrived!

Altogether over 130 man/woman days have been spent at Vallis, but I rush to tell you that this site is not representative. The project has grown bigger than was originally intended because of the enormous enthusiasm. It is to be the showplace for what geological conservation can do. Despite rumours to the contrary we are not actually polishing the rock, but a levelled and seeded area is planned for the amphitheatre-style foreground. We have grown enormously possesive over it. Do we dare erect a chain-link fence and charge a high entrance fee to keep out the hoi-polloi?

There are other sites in the Vale awaiting work. One, a condensed Rheatic-Jurassic sequence, needs very delicate handling, and someone with a head for heights and a ladder. Another small site is a fossil sea-cliff, and it looks as though super-glue could be the answer to this one!

There have been some useful spin-offs from this project. We have met geologists, professional and amateur, from all over the country and, more importantly, they have met the OUGS. The concept is spreading and work has begun at Aust Cliff. Indeed it is now possible at Aust to safely examine beds which previously could only be seen by dangling from the end of a rope.

OUGS members elsewhere may be interested in this work. Maybe you know of a similarly neglected site which may be tackled either as a Branch project or by an individual. If you do not know of such a site then contact Dr. Bill Wimbledon at the Geological Conservation Review Unit of the National Conservancy Council (in Pearl House, Bartholmew Street, Newbury, Berks RG14 5LS) or Dr. Alan McIrdy at the Geology and Physiography Section at Foxhold House (see last issue) for details of sites near you.

Local County Trusts for Nature Conservation have been asked to take up geological conservation as official policy. Some may not have anyone interested enough in geology to get it started and yet have sites in their care which you might be welcomed at. All members of the Geological Society of London have been asked to get involved. Why not get up a group of OUGS members and others and start on your own site?

Those members who live geographically out on a limb may well have a small but precious site on their doorstep. Once or twice a year, with the owner's agreement, vegetation could be cut back to prevent deterioration. A small infilled quarry may have a trench cut against its face to allow access. Members associated with the extraction industry may be able to persuade their employer to put them in charge of a bit of tidying up, and may thereby create a new site worthy of visiting.

It isn't, of course, necessary to work on a regular basis. A team of ten or so may well clean up a site in a day. We at Vallis found it best to have a regular date - the third Sunday of each month. This people could remember and attend when they found it convenient.

There can be no disputing that geological sites need conserving. Yet try convincing the most ardent conservationist of this - see the blank look in their eyes, or the piteous expression, at the idea that a rock needs protecting. So if you really love geology and all that it implies try to give it a bit of assistance. Incidentally its about the best way of making good finds.

BOOK REVIEWS

The Great Unknown

*The Inaccessible Earth** by Geoff Brown and Alan Mussett strives to bring together the few facts we know about the interior of our planet into a coherent whole. Unfortunately the facts are not yet coherent enough to support this sort of approach, and the resulting book is itself rather inaccessible.

As a source of data, in the form of copious tables, graphs and illustrations, this book will prove invaluable to future compilers. Many of the diagrams are associated with captions longer than the descriptions of their relevance within the text, and to skip through the book from table to table, with a glance at the lengthy summaries given at the end of each chapter, will probably answer most students needs. If my experience is anything to go by the text may well prove invaluable to insomniacs!

After an introductory chapter, covering principally the history of the geology of the accessible parts of the Earth, the authors look at the use of seismic recordings in providing data on the interior of the planet, duly acknowledging their primary importance. The various techniques for determining the density profile of the planet are then discussed, but in such a way that the only conclusion I could draw was that any model that does not contradict the few existing measurements would, and does, suffice.

The next chapter left the Earth all together and sent us on a 28 page Who's Who of the Solar System before we were presented, in the next chapter, with the rather startling theory that the Solar System must have been formed as the result of two supernovas taking place in the same area of space within 100Ma. To compound this rather implausable (to me) theory we are asked to presume that these supernovas coincided with periods when an arm of the galactic spiral passed through the thin cloud of material from which the system eventually formed. These rather rare occurrences would make the chances of life elsewhere in the universe very remote, so I was rather comforted by the telling phrase that this theory is supported by the observation that 'new stars sometimes form on the expanding front of a supernova explosion'. When astronomers finally see such an event actually occurring I might believe the theory - but that won't happen in my, or your, lifetime!

At this stage we are only halfway through the book, but I'm afraid it gets no better, with few convincing theories being put forward in the remaining chapters. The inclusion of one figure of the classic pillow lava/dyke section from the Troodos ophiolite complex threw me completely. The theory propounded has the pillow lavas above the vertical dykes. The photograph used to support this theory shows the pillow lavas next to, and therefore presumably cut by, the dykes. Hardly the way to inspire confidence in a theory!

The basic mathematics and science required to understand how the Earth was formed is covered in notes in an Appendix, so avoiding having too many formulae in the text, and the book ends with a comprehensive bibliography and index (the latter being particularly nice to see in this day and age). These features, whilst a help to the browser, do not, however, aid understanding when studying the text in depth.

Whilst this book certainly covers all the standard models put forward to date, placing these models side by side only seems to highlight both the problems with employing models and the basic inaccessibility of the interior of the Earth. *The Inaccessible Earth*, unfortunately, does little to lift the lid on the confusion surrounding the subject.

*Brown, G and Mussett, A (1981) *The Inaccessible Earth*, George Allen and Unwin, 272pp (126 line and 7 tone illustrations), £18 (hardback) or £9.95 (paperback)

The Rhynie Story

At first sight £1.20 seems a lot to pay for a 16pp booklet, but anyone who knows the geological books published by the HMSO will know that they offer excellent value for money, and *Plants invade the land* is no exception. Written for the Royal Scottish Museum in Edinburgh by Bill Chaloner and P. MacDonald, it explains the significance of the finding, over 70 years ago, of well preserved, silicified plant remains within the Rhynie Chert.

As anyone who heard Professor Chaloner during our last Conference will remember, the plants found at Rhynie are still the best preserved collection of plant fossils dating from before the Carboniferous period. The instant preservation of the plants, by their immersion in hot, silicon-rich, volcanic fluid, has enabled geologists to use thin sections to study details such as cell structure and microspore generation. With the help of numerous excellent pictorial reconstructions the authors explain the geologist's findings in a clear, concise style. They even show the evidence for early fungi and insect attack on the living plants.

The booklet is rounded off by a list of further reading which includes two French language publications and a very useful combined glossary of terms and index. All in all a very good introduction to the fascinating fossil record so well preserved in the Rhynie Chert.

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Carry On Howling

Believe it or not, geology has produced some even funnier spelling mistakes than those Mike introduces into the Newsletter! Many of them first appear in exam papers, and now some of the markers who have the good fortune to be paid to read these 'howlers' have been kind enough to make some of the best of them available to us lesser mortals.

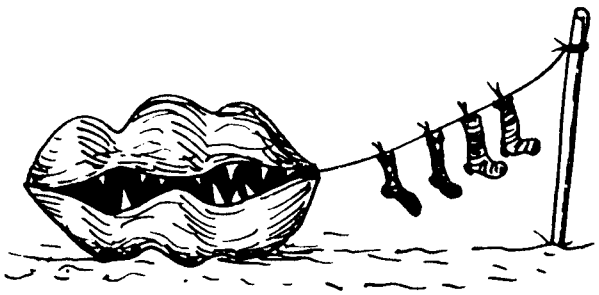
Geological Howlers is a collection of such memorabilia compiled by W. D. Ian Rolfe for the Geological Society of Glasgow. It contains many spelling mistakes of 'The Crustaceous System' type, a few jokes that appear to have been written as such (Fossils in the S. Wales Millstone Grit are Llamelibranchs) and some rather deeper philosophical points, in the vein of:

> 'If footprints are found on the underside of a bed it usually means the bed is inverted as few animals walk upside down underground.'

The 52 pages of such one (or two) liners includes some beautiful geological cartoons based on items within the text. All in all the perfect stocking filler for the geologically minded, so start shopping for Xmas now - then you'll have plenty of time to read it before you have to wrap it up after the exams!.

Geolocial Howlers can be obtained by post from the Geological Society of Glasgow, c/o Geology Department, 'the University, Glasgow GL12 8QQ. The cost is £1 plus 20p postage and packing.

Martin Bryan



Articulate brachiopods have teeth and socks.

Branch Reports

Worbarrow Bay

Mr. Paul Ensom, Assistant Curator of the Dorset County Museum, fresh from his dinosaur dig at Swanage, led an enthusiastic party of 11 OUGS members and friends to view the Purbeck and Wealden at Worbarrow Bay, Dorset on September 13th 1981. The Purbeck Beds can be seen on the western side of the Tout at most states of the tide. The lower beds may also be seen in Pondfield Cove, on the eastern side. The beds have a very steep dip, approximately 40°. Rather naturally we examined the iguanodon footprints in the Roach above the Cinder Bed first. Roach is a quarryman's term for shell-debris limestones in the upper building stones of the Purbeck Beds. The Cinder Bed is a thick (1m!) bed largely composed of *Liostrea distorta*, mainly whole, in a very fine mud matrix. It represents a marine incursion into an area of mainly brackish conditions, and is a widespread marker bed. We found several small pieces of sea urchin spine in this bed. Most of the Purbeck Beds are thin limestones and marls deposited in a highly variable environment. This environment changes to such an extent that an experienced quarryman can pinpoint the source of a quarried stone to within 50m. The section at Worbarrow is noticeably thinner overall than that at Durlston. Continuing southwards on the Tout (down the section) we saw the evaporite deposits - gypsum - which show so well the 'chicken wire' effect and enterolithic folding described in the Sedimentary Basin case study of S335. If you visit this site I must emphasize that hammering is FORBIDDEN in order to preserve this unique exposure.

The junction of the Purbeck and Wealden Beds is obscured by slipped material, but we followed the Wealden Beds around the bay. These consist of sands, silty clays and grits, probably laid down as a fresh water fan deposit. The bright mauves, oranges and yellows are mainly oxides of iron, though sulphur is present around the lignite deposits. Tourmaline and quartz are found in the grit. There are repeated cycles of grit, sand and clay, but the clays are mainly slipped and almost impossible to reach in situ.

The junction between the Upper Greensand and Lower Chalk can only be seen in fallen blocks, whose character changes rapidly. At one point the junction is marked by an unconformity with an eroded, phosphatized surface coated with glauconite. Further round the bay the blocks show a gradual change, with no erosional break. Mr. Ensom considers that a fault must run between the two locations, which gave rise to uplift and erosion on the eastern side. A large cliff fall has occurred in Cow Hole, so that the junction is no longer visible at beach level.

Jo Thomas

South Cotswolds and Mendips Trip

During the weekend of 3rd/4th October 1981 eleven OUGS members attended a field trip, organized by the Oxford Branch, to the South Cotswolds and Mendips, under the leadership of Simon Conway Morris from the OU.

Saturday was spent examining Jurassic rocks, the princpal units in the area being the Liassic Cotteswold Sands and the Inferior Oolite. The Cotteswold Sands form a diachronous unit running south from Stroud to the English Channel at Bridport. The sands are given local names and become progressively younger to the south. Further north rocks of the same age form the Upper Lias Clays. The Inferior Oolites are principally limestones and marls, many of which are fossiliferous. Above the Inferior Oolite you find Fullers Earth, Great Oolite, Bradford Clay and Forest Marble.

Out first stop was at Leckhampton Hill (949185). The Main Quarry exposes a section from the Upper Lias through the Lower Inferior Oolite to the Lower Freestone. The Upper Lias Clays were not seen. The Scissum Beds were examined and found to start with a basal sandstone unit, followed by muddy/sandy limestones with pockets of sand containing brachiopods and other fragments of fossils. Above this the Lower Limestone had a basal bed of ferruginous limestone, containing crinoids, which was succeeded by rubbly limestone. This was followed by the Pea Grit, which is a fossiliferous limestone with pisoliths (pea-sized ooliths). The top exposed bed in the Main Quarry, the Lower Freestone, could not be safely visited on this face so we walked up the hill to the South Quarry.

In the South Quarry the Lower Freestone was the base unit. These mainly oolitic limestones, which were deposited in a high energy enviroment, displayed large-scale cross bedding, generally dipping SW. Above them was Oolitic Marl, which consists of well-bedded limestones with marly partings, which in turn was capped by the Upper Freestone.

The base of the Top Quarry is in the oolitic Upper Freestone limestone. Detailed studies of the calcite suggest that this bed was subject to subaerial weathering prior to the deposition of the overlying Lower Trigonia Grit. The Trigonia Grit, which lies unconformably over the Upper Freestone, has a marly base which is succeeded by ferruginous limestone. No *Trigonia* were seen! The top bed in this quarry was the Gryphite Grit, which is a rubbly, sandy limestone containing many fossils.

We then went on to Birdlip Hill (925146), where a roadside exposure shows Upper Freestone being overlain unconformably by the Upper Trigonia Grit. This was capped by the Clypeus Grit, another misnamed fossiliferous limestone, in which we found specimens of the echinoid *Clypeus ploti* from which the bed gets its name. The Clypeus Grit is separated from the Upper Trigonia Grit by a soft parting.

The next stop was at Leigh's Quarry on Selsley Common (826025). The Lower Freestone at the base of this quarry is oolitic and shows large-scale cross bedding. A bed of Oolitic Marl again separates the Lower Freestone from the Upper Freestone. This limestone has been bored at the top by annelids and the bivalve *Lithophaga*, indicating that there is an unconformity between it and the overlying Upper Trigonia Grit. Clypeus Grit and White Oolite can be seen at the top of the quarry.

Wooton Hill Quarry (753938) was our first contact with the Cotteswold Sands. These Upper Liassic, fine grained, sands and silts form the base of the quarry, and are overlain by the Cephalopod Bed. This is a condensed deposit where a thin and richly fossiliferous sequence of limestones and marls represents deposition over a considerable period of time. The sequence yeilds ammonites, belemnites and bivalves, and ooliths composed of the iron mineral chamosite.

An attempt to look at the Fuller's Earth in Swainswick Road Cutting on the way back to the hotel was foiled by the heavy vegetation!

Sunday was spent examining some of the oldest rocks in the area. There were Silurian volcanics, Lower Carboniferous limestones and some Mesozoic rocks of Triassic and Jurassic age. Some of the Mesozoic rocks were unusual in that they occur as fissure infillings within the underlying Carboniferous. In some cases fossil material, including vertebrate remains, has been swept in with the sediments. We also saw a number of unconformities.

The Emborough Quarries (623505) consist of Carboniferous Zone D Hotwells Limestone. The SE corner has a fissure infill of Triassic age which consists of a lower sequence of well-bedded red clays overlain by a conglomerate containing boulders of Carboniferous limestone. Bones of the gliding lizard *Kuehneosaurus* have been found in this layer, but not by us!

Moving on to Moon's Hill Quarry (662461) we were able to study the oldest rocks in the area, the Silurian volcanics. There was very little volcanic activity in Britain during the Silurian and this is one of the few available outcrops. As they are the oldest rocks in the Mendips they represent the core of the easternmost of the elongate anticlines (periclines) that form the range. The rocks exposed are mainly andesites and rhyodacites, with some steeply inclined tuff bands. There was evidently a lot of shearing and veining, with calcite and epidote in evidence. Apparently fossils have been found in the tuff bands, but none were seen. The volcanics are unconformably overlain by Devonian Old Red Sandstone.

Burrington Coombe (477587) is an attractive feature within the Mendips which exposes almost the complete sequence of Lower Carboniferous rocks of Tournaisian and Visean ages. The beds dip northwards so that walking up the Coombe we passed progressively older rocks as the road (B3134) ran southwards. At the first quarry (47705885) the eastern wall consists of Clifton Down Limestone, a fossiliferous band in which we found corals and brachiopods. In the second quarry (47655875) we examined the top of the Burrington Oolite, which again had brachiopods and corals among the ooliths. After passing the Rock of Ages and Avelines Hole we saw the fossiliferous basal beds of the Burrington Oolite in a third quarry (47705860). Further along the road the coombe turns eastwards where the Great Scarp and Black Rock Limestones are exposed. Chert beds and silicified fossils occur in these beds. From here we ascended a path up the Eastern Twin Stream to see the Lower Limestone Shales at their junction with the underlying Old Red Sandstone. Unfortunately the stream was in spate so we couldn't see the junction!

Our thanks to Simon for a very interesting field weekend.

Ivan Foster

Tortworth's Silurian Inlier

13 members and eight others met at Brook Farm, Falfield, in November for a look at the Tortworth Inlier under the guidance of Dave Green. Our first stop was in Cullimore's Quarry, Charfield Green, where Llandovery Upper Trap amygoidal basalt showing signs of haematitic weathering (red boles) was exposed. It contains xenocrysts of quartz that probably resulted from quartz pebbles being caught up in the lava flow.

After an excellent lunch stop at the Huntingford Mill Hotel we moved on to Damery Quarry to look at the Lower Trap, a serpentised olivine basalt with an apparent dip of 30°SW. The map shows the real dip to be 35°SE, and that the beds form the nose of an anticline. Thin sections have shown evidence of albite, which is not normally found in serpentised basalts. It is probably a secondary product, the original feldspars being of the calcium variety. There is some evidence of autobrecciation, which makes it unlikely that the round structures at the base of the outcrop are pillows (there being no evidence of infilling between pillows).

On the other side of the Little Avon River a roadside bank exposed the Llandovery sandstones and shales of the Damery Beds. One rottenstone band is highly fossiliferous, containing rugose corals and brachiopods. Trilobites are recorded in this bed, but we couldn't find any.

Our last stop was on the other side of the anticline, where the complementary syncline results in the exposure of the lowest Wenlockian limestone in Brinkmarsh Quarry. The limestone dips 22°SW, and is bounded on the north by a calcareous sandstone and on the south by a fossiliferous clay, both of which show signs of

haematite staining that probably resulted from percolation of water through the overlying Triassic, which has since been denuded. A band of celestine (strontium sulphate) within the quarry was probably formed in much the same way. Two pieces were found, but their source was not identified. The crinoidal Wenlockian limestone was very coarse-grained, and contained calcite veins and slickensides. Siltstone bands were found interbedded with it. The clay above the limestone contained well-preserved, whole, specimens of brachiopods, rugose corals, bryozoans and crinoid ossicles.

Martin Bryan

Ravenscar Revisited

During the weekend of June 19th-21st the OUGS made a minor invasion of the North Yorkshire coast between Ravenscar and Kettleness. Twenty or so members from the East Midlands, Yorkshire and Cleveland branches sampled the salt air and Jurassic rocks of the NE coast.

Saturday was blessed with a fine morning, a good low tide and a first-class leader. Alan Staniforth led a relaxed, unhurried, not too technical, excursion along the line of the bifurcating Peak Fault to the beach and, later, into a disused quarry.

Along the line of the fault the shales of the Lower Lias, on the Robin Hoods Bay side, meet the Jet Rock Series of the Upper Lias, on the Blea Wyke side, in what is now believed to be a lateral or tear fault, dated at about 35ma.

As the morning wore on the receding tide exposed more and more of the eroded surface of the Robin Hoods Bay dome, a large-scale feature whose scars sweep around the bay, showing the remains of the Tertiary folding which took place in the area.

Alum was worked in North Yorkshire from the 17th century until about 1870, being used chiefly as a mordant in the dye industry. We marvelled at the strength of the work force needed to remove manually such vast quantites of shale for the production of relatively small amounts of alum, and we picked up some fine specimens of Equisetum.

Sunday was an equally successful day, thanks to the expert knowledge of our leader, Peter Thornton, and to John's dominance over the weather - even casting aside Pat's personal rain cloud (see below)!

From Sandsend car park we walked NW along the track of the old railway line and climbed down to the shore at Deep Grove Wyke, where the Upper Lias shales are capped by the Dogger - a sandy ironstone - and the more massive sandstones of the Lower Deltaic Series.

A thin seam of good quality jet was found in one of the disused and fairly inaccessible mines. Jet is driftwood which has been subjected to chemical action in stagnant water and deep burial within the blue, oily, bituminous Lias shales. It has been worked since the Bronze Age but was in its prime during the Victorian era. Today it is worked by local craftsmen in North Yorkshire.

There were sufficient ammonites to go round - and a few to spare! Most common was *Dactyliocerus commune* but we found *Phyllocerus, Harpocerus* and several which were taken away for identification.

After a fairly steep climb we were ready for the refreshments on offer at Goldsborough before continuing our way to Kettleness, the scene of further alum workings.

Thanks to the thoughtful Ice Age, Arthur was able to extend his reperoire of Shap erratics - we've got big 'uns over here on the Yorkshire coast! Oh - and the saying of the day, on seeing farm animals basking in the noonday sun - "Look at those pigs making humans of themselves"!

We all had a great weekend and thank Alan and Peter for being such marvelous leaders. We look forward to doing something similar next year.

Shap Revisited (Again!)

"Let it be understood that I am responsible for the accommodation, not the weather."

Thus spake John-of-the-sunny-field-trips at the start of a slightly damp weekend. Our intentions were good - to study the Ordovician inlier of Tathyes Beck, various localities along the River Rawthey, the area east of Shap on Orton Scar and the Shap Granite Quarries.

Some fine specimens were collected from the granite quarry and some attractive pieces of crinoidal limestone were found near Orton, but any attempts at serious geology were quickly soaked to a soggy pulp as we wellied our way up Tathyes Gill, trying desparately to reach localities on the map before they dissolved in our hands.

This is how the story should have unfolded: the Ordovician inlier of Tathyes Beck lies almost totally east of the Sedburgh-Kirkby Stephen road and is bounded on the east by the Dent Fault. It is an eroded dome, trending NE-SW, extensively faulted and intruded by numerous felsite and lampophyre dykes and sills emanating from the Shap granite intrusion. Lithologically the area consists of highly cleaved, leaden-grey, Ashgill Shales, nodular calcareous mudstones and the Coniston Limestone, which is zoned in a series based on brachiopods and trilobites.

Our story, however, is slightly less geologically specific. We splodged about 800m up Foxhole Rigg Lane, which runs parallel to the felsite sill, and waded through

Tethyes Farm and down the stream which has cut a gorge through the sill. The contact between the top of the sill and the limestone was not seen, but one of the many faults was found. Thick drift covering the east bank provides a rich foundation for the tangle of trees we encountered. Although the precipitation from above and the speed and depth of the gill below claimed many victories, two dedicated war lords journeyed on to the death in search of (and finding) the Dent Fault.

I would like to take this opportunity of thanking out very enthusiastic leader, Miss Iris Bracken, for the work she put in before and during the weekend. Perhaps next year.....?!!

Princess Ranier

(Who appears to live somewhere north of Watford - Ed.)

Field Excursion to Cayton Bay

On Saturday October 3rd about a dozen members and friends met at Cayton Bay car park for what promised to be a most enjoyable field trip. With a slight 'nip' in the air and a good low tide we took the footpath to the bay. Cayton is a pre-glacial bay, infilled with boulder clay deposited at what our leader, Richard Pepper, described as 'the Clapham Junction of glaciers'. From the rich brown clay our finds included limestone with brachiopods, probably from the Pennines, rounded fragments of white granite, possibly from Scandinavia, pink granite from Scotland, Shap granite, coarse gabbro and finer dolerite, limestone showing colonial corals,.....

Noting the typical landslip features where boulder clay has slipped along fracture planes, we progressed to the Kellaways Rock of the Upper Jurassic, with its typical, highly inclined, jointing. Trace fossils (burrows) and fossil wood were found in these shallow-water deposits, which are often oolitic and iron-rich.

The younger, greyish, Oxford Clay, seen next, was said to be much thinner here than further south. We found the Red Cliff Fault, which runs through a gully and has a considerable down-throw to the north. Here the cap of Lower Calcareous Grit found over much of the deposits around the bay is missing.

Sandstones showing well defined cross-bedding were noted within the Middle Deltaic Scalby Formation. Below these were a white ganister with good examples of plant rootlets and, along the shore a bit, the Yons Nab Beds, with its characteristic hummocky, iron-stained, top. Good examples of cross-bedding were also seen in the water-lain dune formation of the very tough, grey, Millepore Limestone.

We finished our excursion near an old wrecked ship beyond Yons Nab, where the Scarborough Beds are interrupted by a deep washout channel filled with contorted Upper Deltaic deposits.

Pat Tye

Market Weighton

Last August members from the Yorkshire Branch followed Archie Moore around the geological sites surrounding Market Weighton.

We started with the classic section through the Market Weighton upwarp at the Rifle Butts at Goodmanham, where we saw the Upper Cretaceous Red Chalk and Carstone lying unconformably on the Jurassic Lower Lias. Kiplingcotes Nature Reserve showed the base of the Upper Chalk and contained scattered flints and sparse fossils, but the same bed in a roadside exposure nearby produced the zone fossil *sternotaxis planus*. We also saw occasional highly fossiliferous lenticles (referred to as the Kingscote lenses) of iron-stained material at this location.

Moving on to North Cave 'Ice Raft' we saw a large mass of Cretaceous flint and chalk rubble overlain by Middle Jurassic Cave Oolite. Stather explains the inversion of the strata as 'ice-rafting', the Jurassic material being carried across the then Lake Humber by ice at the end of the last glacial episode.

At South Cave Station Quarry we saw Upper Jurassic Kellaway Sands, which had thin ferruginous bands and two rows of hard limestone concretions (doggers) in the upper part. The overlying orange-brown sandstone is called the Kellaways Rock.

Our last stop was at Kettlehope Quarry, South Cave. Again the Kellaways Rock is exposed, but here it was much more fossiliferous. Numerous belemnites, rhynchonellids, and occasional ammonites, are found, and there is a prominent double oyster band (*gryphaea bilobata*) near the base of the overlying sandstone.

Archie Moore

Tale of a Trip?

Have you ever noticed that when you haven't any responsibility (physical, legal, moral, academic, etc) its 'us' and 'him'? And when you do have responsibility its 'me' and 'them'?

The original idea for this episode was simply to examine the Lower Palaeozoic rocks of Crummackdale. Therefore, after a bit of research and armed with a lot of good intentions (the road to the Yorkshire Branch AGM is paved with them), I volunteered to lead a field meet there. In writing!

Within five minutes it had expanded from a day trip to a Weekend Geological Excursion. By the time the Newsletter was published the word 'mapping' had evolved (obviously a Creationist was at work). More obviously, the situation was rapidly getting out of control. Fighting down stage fright, panic and the urge to emigrate, I thought I'd better get down to some consistent, coldly logical, preparation. Particularly on-site.

A week later the most severe winter for many years had clamped down. As far as on-site preparation was concerned, the 'cold' bit was incredibly easy. The weather supplied the 'consistency' and so, by mid-January, only the logic was outstanding. (I was insitting, by a licenced fireplace.) The time had come for more thinking and less drinking, or vice versa.

There were, or appeared to be, several factors in my favour. For instance, they can't go and buy the Geological Survey map of the area, because there isn't one*. Secondly, it isn't a well frequented area, so they may not know where it is. Thirdly, if they know where it is, they probably don't know the local geography. Fourthly, if they do, they'll know that most of it is private farm land, so I can easily avoid the difficult bits.

The snag is, what do we do when we get there? Alas! I need to apply some intelligence. (Thinks, bottled or from the wood?)

Why not get *them* to do the work? Point them at some of the evidence and get them to do the describing and measuring and recording? Geology the right way round for a change: collect some evidence and put it together, rather than dash from locality to locality ticking off items on a list. With a bit of luck people who have done S23- won't have a compass and clinometer, and those taking the course won't know how to use OU instruments.

* This is a half† truth
†Literally!

Why not put them off by pointing out that the ground is rough or steep or wet, or any combination of all three? Can I risk winding up with a bunch of Olympian geniuses? (Thinks: genii? - no, they come out of lamps.)

Why not start off with some limestone, so they think that the last came first and the first last? That ought to prove the Creationist theory at the expense of Evolution.

Why not put them off by saying that if it rains they'll be half drowned (no shelter) and if its sunny they'll be flayed alive (no shade)?

Why not concentrate attention on the 50 million years or so missing from the middle? That sounds a good idea - we can compare it with some of the negative limestone sitting on top of it.

Why not (master stroke, this) take them to Castlebergh, as an afterthought, first. They'll be as bent as the basement on top! (I will be as holy as the limestone.)

And why not send in a field meet report before the event? If the Editor's desperation for copy overcomes his commonsense and he publishes it, that should be a notable innovation. Confusion should be complete. They'll think they've missed it and so won't turn up!

Alan Brittain

Who says I have commonsense? I hope I can get to this enticing, if potentially confusing, morsel on June 5-6th. Why not join me in confounding the 'expert'. Ed.

Editorial

Bet you thought you'd got away without having to read one of my missives. Actually, I couldn't see any way of filling two pages at the front, so I thought I'd fill the one gap that was left after I'd set the articles we were priveleged to receive. (That doesn't mean I'm not still waiting for your contribution - there's nothing left in the woodpile!) If you've got this you've joined for 1982, so you will be able to vote to accept (or reject) the proposed changes to the Constitution at the Special General Meeting in July (at Reading, following the Conference). If you didn't get this you haven't rejoined - so how come you're reading my missive?¿?

Obviously I'm reduced to rambling on again, so now is the time to quit. One final thought - take a special look at the last of the Branch Reports - it's a corker!

Martin Bryan

Permian Permutations

Our tutors are not in disgrace
They don't have to do 'about face'
The lecture last night
Showed that they were right
And Gareth will doubtless shout 'Ace'

But

That Welshman from Kent, in a tie-up
Describing a site we saw high-up
Called it Rye-hope
(to rhyme with soft soap)
And not, as it should be, Ri-up

Then Mavis gave us a chat
About fore-reefs, back reefs and all that
And dolomite slumps
And algae, in clumps
Was she speaking right through her hat?

Chris knows all there is about veins
And tells us all as it rains
When we go out to see
Just what they could be
Our hands and feet freeze, and our brains

Ruth Morant went with us to see
What geology can really be
It rained all the day
And she was heard to say
'Its back to physics for me'

And so we disperse from the school
Feeling not quite so damn-fool
As we did when we came.
Do we all feel the same?
Then let Geol 777 rule.

Sic Fransit Gloria Geologica
(so pass the glories of geology)

David Cornubeusis

To the tune 'Guide me O Thou Great Redeemer' -

On our field week up in Durham,
We have trod the country through,
Though our samples are a poor set
We are bringing back a few.
Permian Sandstone, Pink Shap Granite,
With a bit of limestone too,
With a bit of limestone too.

Sunday morning on the coaches,
We began a busy week,
To the Whin Sill after the lunch break,
Then the quarry we did seek.
On to Frosterley, where the corals be,
Seeking samples by the score,
Seeking samples by the score.

When we trod the heights of Hillbeck,
All our anxious fears subside,
When the faults reveal thier 'max's'
With our tutors by our side.
Oh! such tutors, wondrous tutors,
And the demonstrators too,
And the demonstrators too.

On to Wednesday - what a coach trip,
To the Brockham we did go.
Lunch at Shap Wells - and a pie treat,
It's a wondrous taste you know,
On to Blea Beck, see the contact,
And the streaked-out lava flow,
And the streaked-out lava flow.
You try fitting vesicular in!

Optional last verse only for those who have experienced a John Wright week
Meanwhile in St. Mary's offices,
John Wright's wondering what to do,
With his helmet and his wellies,
He is waiting for his crew,
Do not worry, do not worry,
We've a sample just for you -
It's a bit of Shap so blue!

Norma

To the tune 'On the twelfth day of Christmas' -

On the tenth day of field trip my tutor showed to me -
Ten students flagging, nine miles a'walking, eight way-up structures,
Seven limestones fizzing, six beds a'dipping,
Five granite tors, four basalt dykes,
Three thrust faults, two brachiopods,
And an outcrop in a green field.